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Contents

Original Paper

Testing of a Self-administered 6-Minute Walk Test Using Technology: Usability, Reliability and Validity Study

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Abstract

Background: The need to attend a medically supervised hospital- or clinic-based appointment is a well-recognized barrier to exercise participation. The development of reliable and accurate home-based functional tests has the potential to decrease the burden on the health care system while enabling support, information, and assessment.

Objective: This study aims to explore the usability (ie, acceptability, satisfaction, accuracy, and practicality) of the EasyMeasure app to self-administer the 6-minute walk test (6MWT) in young, healthy adults and determine parallel form reliability and construct validity of conducting a self-administered 6MWT using technology.

Methods: We used a usability study design. English-speaking, undergraduate university students who had access to an iPhone or iPad device running iOS 10 or later and self-reported ability to walk for 6 minutes were recruited for this study. Consenting participants were randomized to either a standard 6MWT group (ie, supervised without the use of the app) or a technology 6MWT group (ie, unsupervised with the app to mimic independent implementation of the test). All participants performed a maximal treadmill test. Participants in the 6MWT group completed the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire and a satisfaction questionnaire after completing the assessment. Parallel form reliability of the 6MWT using technology was analyzed by comparing participant self-administered scores and assessor scores using Pearson correlation coefficients across and between trials. Construct validity was assessed by comparing participant 6MWT scores (both standard and using technology) with maximum treadmill test variables (peak oxygen uptake and ventilatory threshold [VT]).

Results: In total, 20 university students consented to participate in the study. All but 2 participants (8/10, 80%) in the technology 6MWT group had deviations that prevented them from accurately conducting the 6MWT using the app, and none of the participants were able to successfully score the 6MWT. However, a significantly strong correlation was found (r=.834; P=.003) when comparing participants' scores for the 6MWT using technology with the assessors' scores. No significant correlations were found between maximal treadmill test peak oxygen uptake scores and 6MWT prediction equations using standard 6MWT scores (equation 1: r=0.119; P=.78; equation 2: r=0.095; P=.82; equation 3: r=0.119; P=.78); however, standard 6MWT scores were significantly correlated with VT values (r=0.810; P=.02). The calculated submaximal treadmill scores and assessor 6MWT scores using technology also demonstrated a significant correlation (r=0.661; P=.04).

Conclusions: This study demonstrated significant usability concerns regarding the accuracy of a self-administered 6MWT using the EasyMeasure app. However, the strong and significant correlation between the 6MWT and VT values demonstrates the potential of the 6MWT to measure functional capacity for community-based exercise screening and patient monitoring.

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Introduction

Background

Tests of mobility, physical functioning, and aerobic capacity are commonly used in research and clinical practice to evaluate the impact of exercise programs [1] and for prognostic prescreening and risk management purposes (eg, identifying individuals at risk for complications related to certain medical conditions and exercise participation) [2]. However, the need to attend a medically supervised hospital- or clinic-based screening assessment is a well-recognized barrier to exercise participation [2,3]. This barrier is likely heightened for individuals who are older, are living in rural and remote communities, are living with chronic conditions that limit their functional independence, and lack accessible health care services.

In Canada, there is a rapidly growing aging population wherein 1 in 4 adults live with 2 or more chronic conditions, and half of older adults live with three or more chronic conditions [4-6]. Furthermore, many individuals live in remote and rural communities, limiting health care availability. Therefore, it is becoming increasingly important to develop simple, self-administered, and home-based functional tests for community physicians and rehabilitation professionals to facilitate distance-based risk screening and pre-exercise clearances. The development of reliable and accurate home-based functional tests has the potential to decrease the burden on the health care system while enabling support, information, and assessments.

The 6-minute walk test (6MWT) is an easy to perform, submaximal, and widely used test of functional exercise capacity [7]. It is used clinically as an objective measure of functional status to determine appropriate exercise prescription and predict morbidity and mortality [7]. It measures the distance covered in 6 minutes, with the objective being to walk as far as possible at a comfortable pace within those 6 minutes [7]. The 6MWT has been used in people across the lifespan (eg, aged 2-65+ years) and a range of health conditions (eg, stroke, pulmonary diseases, osteoarthritis, and dementia) [7], with established age- and condition-specific normative data available by sex [1]. The 6MWT has demonstrated responsiveness to assess change in functional exercise capacity, and minimal clinically important differences for various populations, ranging from 19 to 49 m, have been established [8,9]. In addition, the ability to walk approximately 288 to 300 m in 6 minutes has been suggested as a threshold for functional independence and community ambulation [10,11]. As the 6MWT is widely used clinically as a test of functional exercise capacity, it is important to validate its ability to estimate peak oxygen uptake (VO_{2peak}) to ensure its outcomes are being used safely and reliably. A cardiopulmonary exercise test (CPET) is the gold standard for assessing VO_{2peak}. However, CPET requires specialized equipment and personnel that are not widely available, particularly in rural and remote communities. Currently, correlation coefficients for the 6MWT and VO_{2peak} reported in the literature range in value [12,13]. Given this evidence and the common clinical use of the 6MWT, it is important for researchers to continue to explore the accuracy of estimating VO_{2peak} from 6MWT data using a variety of predictive equations.

The EasyMeasure app [14] shows the distance from the phone to an object, as seen through the lens of the iPhone or iPad camera. It is free to download on any Apple iPhone, iPad, or iPod device that has iOS 10.0 or later installed. This app can be useful in conducting a self-administered 6MWT by allowing users to measure the distance to an object before beginning the walking test. This could aid in calculating the total distance walked at the end of 6 minutes. The EasyMeasure app does not include a lap counter or timer as part of its functions. To date, no study has assessed the use of the EasyMeasure app as a tool to self-administer the 6MWT in any population.

Objective

The primary objective of this study is to explore the usability (ie, acceptability, satisfaction, accuracy, and practicality) of the EasyMeasure app to self-administer the 6MWT in young, healthy adults. Our secondary objectives are to determine the parallel form reliability and construct validity of conducting a self-administered 6MWT using technology. The results of this trial in a healthy young adult population will help determine the updates and changes necessary for successful implementation before use with other populations.

Methods

Study Design

A usability study design was used to test the app characteristics, parallel form reliability, and construct validity of conducting a self-administered 6MWT using technology in a controlled setting. Participants were asked to perform either a self-administered 6MWT using the EasyMeasure app or a traditional investigator-supervised 6MWT in the laboratory. All participants were also asked to perform a maximal treadmill test for aerobic capacity. The University of Toronto Research Ethics Board approved this study (#37108).

Participants and Recruitment

We recruited 20 undergraduate university students via email within the Faculty of Kinesiology and Physical Education and among varsity athletes from the University of Toronto. Eligible participants included (1) English-speaking (2) undergraduate university students (3) younger than 30 years (4) who had access to an iPhone or iPad device running iOS 10 or later, (5) were willing to download the EasyMeasure app on their device, and (7) self-reported being able to walk for 6 minutes. Potential participants were excluded from the study if they (1) self-reported having any physical injury or condition that precluded them from walking safely for 6 minutes or (2) self-reported a cognitive condition that precluded them from understanding instructions or the consent form provided. Interested respondents contacted the study investigators to schedule an assessment session date and time. All participants were required to complete written informed consent before beginning the project.

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Procedure

Preparation

Eligible consenting participants were randomized to either the standard 6MWT group (ie, supervised without the app) or the technology 6MWT group (ie, unsupervised with the EasyMeasure app to mimic independent implementation of the test). Before the testing session, all participants were asked to download the EasyMeasure app onto their devices. Upon arrival at the testing sessions, participants were informed of which version of the 6MWT they would complete. Participants' heart rate, blood pressure, rate of perceived exertion (RPE), and oxygen saturation levels were assessed before and after the testing sessions to ensure participant safety.

Standard 6MWT

Participants in the standard group were given the 6MWT instructions by an assessor (physiotherapist [JST] or exercise physiologist [SCA]). Participants were asked to walk as quickly as possible in a comfortable manner for 6 minutes along a previously measured straight pathway. During the test, participants were timed by the assessor and given standard encouragement at each minute interval. The assessor counted the number of laps performed by each participant. At 6 minutes, participants stopped at their location along the path, and the assessor measured the total distance walked for the final lap. The assessor calculated the total distance walked in 6 minutes and interpreted the participants' test scores.

6MWT Using Technology

Compared with the standard 6MWT group, participants in the technology group had to measure the distance between objectives (measure the test path), time the test, and count laps independently. To accomplish this, participants in the technology group were given instructions by the assessor on how to use the EasyMeasure app (including instructions for proper calibration of the app as well as how to measure the distance to an object and how to take a photo of the distance recorded), how to perform the 6MWT, and how to interpret their 6MWT scores. Participants used the app to measure the distance from the starting point to a predefined object. They recorded the distance between the starting point and the object by taking a still image using the app. Participants then walked consistently for 6 minutes around the 2 objects. Independent of the EasyMeasure app, they timed themselves using their cell phones and counted laps (either within their head or with the counter function on their phone). At the completion of the 6 minutes, they used the EasyMeausre app to measure the distance walked along the path during their final lap. They recorded this distance by taking a still image using the app. After performing the test, participants calculated the results of their test (ie, how many meters they walked in 6 minutes) by multiplying the number of laps walked by the distance measured in the app. They then interpreted their test scores by comparing their 6MWT score with provided normative values for age and sex (ie, determine if their scores were within normal limits for their age range and state if they were safe to exercise independently based on results).

This test was performed autonomously but in the laboratory. An assessor was present but did not interfere with or provide encouragement. The assessor knew the distance from the starting line to the object of measurement and counted the laps the participants completed to track accuracy; however, participants were not aware of the assessor's count. The assessor also made notes on the number of deviations to instructions made by participants, the ability of participants to successfully report and interpret their scores, and if any additional resources were needed by participants.

After completing the test, participants in this group completed the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire and a satisfaction questionnaire. The UTAUT is an 18-item self-report measure used to explain individuals' intentions to use a form of technology. It holds four key constructs, including (1) performance expectancy (the extent to which the individual believes that use of the technology will lead to improved health), (2) effort expectancy (how easy was the use of technology perceived to be), (3) social influence (the extent to which an individual believes that others want them to use this technology system), and (4) facilitating conditions (to what extent did an individual believe there is the organizational and technical infrastructure to support the use of this process) [15]. Each item was graded on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) [15]. The satisfaction questionnaire allowed individuals to describe the positive and negative aspects of using this approach to conduct a 6MWT and their thoughts on the practicality of performing these tests in this manner alone at home. The survey had 8 questions that were measured on a 7-point Likert scale from 1 (not at all) to 7 (extremely) and two open-ended questions at the end where participants gave additional details as to what they liked and did not like about using the app to perform the 6MWT. This survey was pilot-tested by a study investigator in a previous project [16].

Maximal Treadmill Test

Following the 6MWTs, VO_{2peak} was assessed via a CPET on a treadmill under the supervision of a certified exercise physiologist (SCA) using an individualized protocol [17]. Briefly, participants began by performing a 5-minute warm-up at a 0% incline at a belt speed sufficient to elicit approximately 60% of their age-predicted maximal heart rate. The test continued using the constant individualized belt speed established during the warm-up, with the incline increasing by 2% every 2 minutes until exhaustion. Participants' oxygen uptake (TrueOne 2400, Parvo Medics) and heart rate (FT4 HR monitor, Polar) were measured continuously. Blood pressure and RPE were recorded every 2-4 minutes. VO_{2peak} was defined as the highest 15-second average value for oxygen uptake recorded during the test. The maximal effort was defined as participants achieving at least two of the following criteria: (1) leveling off of oxygen uptake despite an increase in workload, (2) respiratory exchange ratio >1.1, and (3) RPE ≥9/10 [18]. The ventilatory threshold (VT) was estimated using the V-slope method [19].

Sample Size

The sample size for this study was determined based on informal guidelines for usability (ie, acceptability, satisfaction, accuracy, and practicality), suggesting a group size of 3-20 participants

[20]. By the end of the trial, we ensured that no new problems arose during subject performance (saturation of data) to ensure we had included enough participants to address the main study aim.

Data Analysis

Quantitative data were summarized using descriptive statistics (ie, means and SDs reported for continuous data; frequencies and percentages reported for categorical data). The open-ended survey questions were analyzed using qualitative descriptive analysis, and responses were grouped into meaningful categories that arose from the data. Parallel form reliability of the 6MWT using technology was analyzed by comparing participant self-administered scores with assessor scores using Pearson correlation coefficients across and between trials. A t test was used to determine the statistical significance between the assessor and participant scores. Construct validity was assessed by comparing participant 6MWT scores (both standard and using technology) with CPET-derived variables (ie, VO_{2peak} and VT). As there is no standardized way to convert 6MWT values to VO_{2peak} estimates, 3 commonly used predictive equations were used to estimate VO_{2peak} from 6MWT scores for each participant. Using 3 different equations, as opposed to choosing one, allowed consideration of a larger scope of possible VO_{2peak} values when comparing outcomes. The estimated

VO_{2peak} values for each equation were then plotted on a scatterplot to identify the outliers. The remaining scores were then correlated to actual VO_{2peak} values obtained from the maximal treadmill test using Spearman correlation coefficients across and between trials to determine the strength of the relationship. The correlations between the 6MWT and VT values were similarly assessed using Spearman correlation coefficients to examine the ordinal relationship between the 2 variables. All statistical analyses were conducted using STATA (version 15, StataCorp) with the significance set at $P<.05$.

Results

Participant Characteristics

In total, 20 university students consented to participate in this study; 10 participants were randomized to each group. Most participants (16/20, 80%) were female with a mean age of 20.1 (SD 2.2) years. Participants had a mean height of 165.8 (SD 7.8) cm and a mean weight of 65.0 (SD 10.9) kg. Participant characteristics and VO_{2peak} estimates for each group are shown in Table 1. Overall, participants in the standard 6MWT group walked significantly further during the test than those in the self-administered 6MWT group (mean difference 163.4, 95% CI 95.4-231.5; $P=.001$).

Table 1. Participant characteristics and 6MWT[a] results.

Characteristic	Standard 6MWT group (n=10)	6MWT using technology (n=10)
Age (years), mean (SD)	20.6 (2.91)	19.5 (1.18)
Sex (female), n (%)	8 (80)	8 (80)
Height (cm), mean (SD)	168.22 (6.87)	163.44 (8.22)
Weight (kg), mean (SD)	65.55 (11.17)	65.52 (11.36)
6MWT distance (m), mean (SD)	658.74 (62.69)	495.30 (80.95)[b]
VO_{2peak}[c] estimate 1[d], mean (SD)	23.74 (1.88)	19.56 (4.75)
VO_{2peak} estimate 2[e], mean (SD)	24.45 (1.62)	21.41 (3.78)
VO_{2peak} estimate 3[f], mean (SD)	20.10 (1.44)	16.90 (3.64)

[a]6MWT: 6-minute walk test.

[b]Assessor score.

[c]VO_{2peak}: peak oxygen uptake.

[d]Peak oxygen uptake = 0.03 × distance (m) + 3.98 [21].

[e]Peak oxygen uptake = 0.02 × distance (m) − 0.191 × age (years) − 0.07 × weight (kg) + 0.09 × height (cm) + 0.26 × (rate pressure product × 10^{-3}) + 2.45 [21].

[f]Peak oxygen uptake = 4.948 + 0.023 × distance (m) [22].

Usability Outcomes

A total of 10 participants completed the 6MWT using this technology. All but 2 participants (8/10, 80%) had deviations that prevented them from accurately conducting the test using the EasyMeasure app. This included 60% (6/10) of participants who lost the count of laps, 40% (4/10) who did not walk at their maximum pace, and 10% (1/10) who did not measure the distance of their last lap.

None of the participants were able to successfully score (ie, calculate the actual distance covered in 6 minutes) the 6MWT; 60% (6/10) of participants did not count the number of laps correctly, and 60% (6/10) measured the distance of each lap incorrectly by ≥0.5 m. In total, 30% (3/10) of participants interpreted their scores incorrectly, reporting that they were within normal limits for their age and sex when they were not; 40% (4/10) of participants identified that they required additional resources to conduct the test successfully, with 20%

(2/10) of participants suggesting the need for a lap counter and a calculator.

UTAUT Questionnaire

Table 2 summarizes the participants' responses to the UTAUT questionnaire. All effort expectancy question scores had a median value of 4 (agree) or better, demonstrating that participants found the process of conducting the 6MWT using the EasyMeasure app easy to perform. The median scores for all facilitating condition questions were high (at 5, strongly agree) and low for technology anxiety questions (2 or less, disagree), indicating that participants felt they had appropriate knowledge and skill to comfortably use the EasyMeasure app to perform the 6MWT. When asked if they would be willing to use a system such as this in their health care, most participants indicated that they would (demonstrated by a median score of 4, agree).

Table 2. Unified Theory of Acceptance and Use of Technology results.

Question	1 (strongly disagree), n (%)	2 (disagree), n (%)	3 (neither disagree or agree), n (%)	4 (agree), n (%)	5 (strongly agree), n (%)	Mean score (SD)
PE[a] (out of 15)						10.3 (1.25)
PE1	0 (0)	1 (10)	6 (60)	3 (30)	0 (0)	3.2 (0.63)
PE2	0 (0)	0 (0)	2 (20)	7 (70)	1 (10)	3.9 (0.57)
PE3	0 (0)	1 (10)	6 (60)	3 (30)	0 (0)	3.2 (0.63)
EE[b] (out of 15)						12.8 (1.75)
EE1	0 (0)	0 (0)	1 (10)	6 (60)	3 (30)	4.2 (0.63)
EE2	0 (0)	0 (0)	1 (10)	4 (40)	5 (50)	4.4 (0.70)
EE3	0 (0)	0 (0)	1 (10)	6 (60)	3 (30)	4.2 (0.63)
SI[c] (out of 15)						9.60 (2.01)
SI1	1 (10)	3 (30)	5 (50)	1 (10)	0 (0)	2.6 (0.84)
SI2	0 (0)	0 (0)	4 (40)	5 (50)	1 (10)	3.7 (0.67)
SI3	1 (10)	2 (20)	2 (20)	3 (30)	2 (20)	3.3 (1.34)
FC[d] (out of 20)						18.9 (2.60)
FC1	0 (0)	0 (0)	1 (10)	1 (10)	8 (80)	4.7 (0.67)
FC2	0 (0)	0 (0)	1 (10)	1 (10)	8 (80)	4.8 (0.79)
FC3	0 (0)	0 (0)	1 (10)	0 (0)	9 (90)	4.8 (0.63)
FC4	0 (0)	1 (10)	0 (0)	1 (10)	8 (80)	4.6 (0.97)
ANX[e] (out of 15)[f]						4.3 (1.15)
ANX1	7 (70)	3 (30)	0 (0)	0 (0)	0 (0)	1.3 (0.48)
ANX2	4 (40)	5 (50)	1 (10)	0 (0)	0 (0)	1.56 (0.70)
ANX3	5 (50)	4 (40)	1 (10)	0 (0)	0 (0)	1.6 (0.70)
B[g] (out of 10)						5.9 (2.33)
B2	2 (20)	3 (30)	2 (20)	2 (20)	1 (10)	2.7 (1.33)
B3	1 (10)	2 (20)	1 (10)	6 (60)	0 (0)	3.2 (1.14)

[a]PE: performance expectancy.

[b]EE: effort expectancy.

[c]SI: social influence.

[d]FC: facilitating conditions.

[e]ANX: technology anxiety.

[f]Performance expectancy, effort expectancy, social influence, facilitating conditions, behavioral intention to use scales: a higher score is better (eg, higher performance expectancy); for the technology anxiety scale, a lower score is better (lower anxiety).

[g]B: behavioral intention to use.

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Satisfaction Questionnaire

Table 3 summarizes the participant responses for each question of the satisfaction questionnaire. When asked about the positive aspects of the 6MWT using technology, 60% (6/10) of participants appreciated that it was easy to use and set up, 50% (5/10) liked that it was accessible and free for everyone, 30% (3/10) appreciated the accuracy of measurement, 10% (1/10) liked that it could be used at home, and 10% (1/10) liked that it was quick to perform. Negative aspects reported by participants included that the app did not provide information directly related to the 6MWT (reported by 5/10, 50% of participants). Specifically, the app did not count the number of laps completed, and they had to calculate the total distance walked on their own. Moreover, 20% (2/10) of participants did not like that the distance between the 2 objects was small. Other negative aspects included that the app had distracting advertisements (1/10, 10%) and required a smartphone (1/10, 10%). Only 10% (1/10) of participants questioned the accuracy of the app's ability to measure distance.

Table 3. Satisfaction questionnaire results.

| Question	Median score[a]
1. How logical does the use of the EasyMeasure app to conduct a self-administered 6MWT[b] seem to you?	5.5
2. How scientific does this way of testing the 6MWT seem to you?	5
3. How complete does this way of testing the 6MWT seem to you? In other words, do you think this method covers all of the necessary steps of performing this test to get an accurate value? Would you need any other resources?	5
4. To what extent would this form of self-evaluation help an individual assess their performance capacity?	5
5. How likely would you be to use this method to assess your 6MWT score if it was available to you?	4.5
6. How likely would you be to assess your 6MWT score in this capacity at home, compared to having a certified health care professional perform this test for you at another location?	5.5
7. How effective do you think this method to assess a 6MWT score would be for most people?	4
8. If a close friend or relative wanted to assess their walking capacity, would you recommend they use this method to test?	5

[a]Scored from 1 (not at all) to 7 (extremely).

[b]6MWT: 6-minute walk test.

Reliability

A significantly strong correlation was found (r=0.834; P=.003) when comparing participants' scores (self-determined total distance walked) for the 6MWT using technology with the assessors' scores (actual distance walked). No statistically significant difference was found between the participant and assessor scores (t_9=0.4319; P=.67). However, when comparing differences between participant and assessor scores, all values were greater than the 6MWT mean clinically important difference (MCID) values, demonstrating inaccuracy between the 2 measures. Figure 1 shows a comparison of the assessor and participant scores.

Figure 1. Participant versus assessor scores using 6-minute walk test technology.
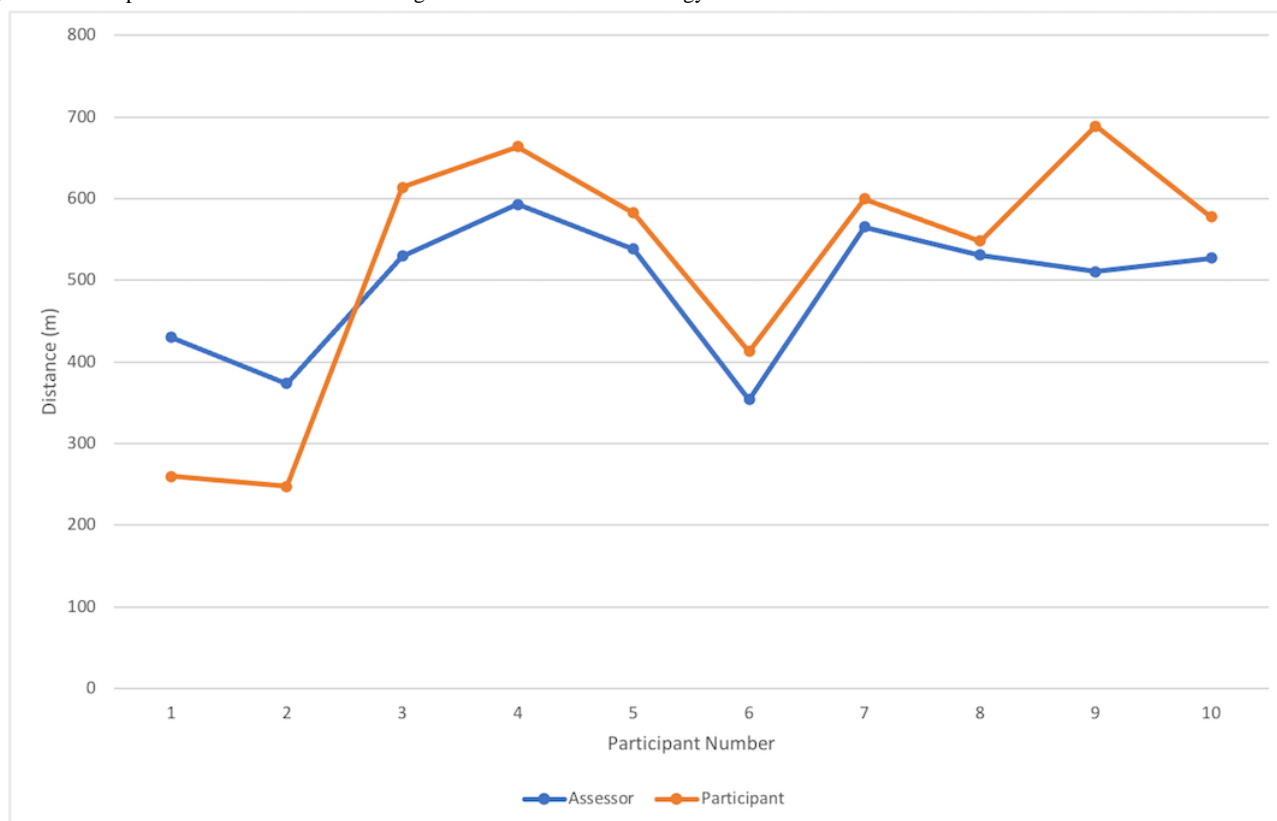
Validity

Standard 6MWT

After reviewing the outcomes on a scatterplot, two participant scores were removed as outliers. The remaining scores demonstrated no significant correlation between maximal treadmill test VO_{2peak} scores and any of the 6MWT prediction equations using the standard 6MWT scores (equation 1: $r=0.119$; $P=.78$; equation 2: $r=0.095$; $P=.82$; equation 3: $r=0.119$; $P=.78$). However, the 6MWT scores were significantly correlated with VT values ($r=0.810$; $P=.01$).

6MWT Using Technology

Owing to inaccuracy in participant scores when performing the self-administered 6MWT using technology, comparisons were only made between assessor scores and maximal treadmill test VO_{2peak} scores. After reviewing the scores on a scatterplot, no outliers were removed. A significant correlation was found between equation 2 and the 6MWT scores (equation 2: $r=0.721$; $P=.02$). No significant correlations were demonstrated for the 2 other equations (equation 1: $r=0.576$; $P=.08$; equation 3: $r=0.576$; $P=.08$), although it is acknowledged that the correlation coefficients are at least moderate in strength and may suggest meaningful associations. The calculated submaximal treadmill scores and assessor 6MWT scores using technology demonstrated a significant correlation ($r=0.661$; $P=.04$).

Assessor Feedback and Learnings

After observing the participants in the 6MWT group, the assessor noted commonalities in participant behavior. First, many young adults in this group were not perceived to be

walking at their maximum speed, as instructed by the assessor. It appeared to be difficult for this group to multitask (walk, count laps, and time themselves) and correctly interpret their 6MWT scores. For example, even when scores obtained were below normal age-matched values (most often due to not walking at maximum walking speed), they often said they were *safe to exercise* based on their perception of their overall health. Together, these observations may help to explain the inaccurate findings of participants in the technology 6MWT group when compared with those in the standard 6MWT group.

Discussion

Principal Findings

The usability, reliability, and validity of conducting a self-administered 6MWT using a distance measurement app was explored among healthy young adults. The results of this study suggest that participants accepted the EasyMeasure app to perform the 6MWT. However, a primary finding of this study is that participants were unable to accurately self-administer and interpret the results of the 6MWT using this app. This finding suggests that the autonomously implemented 6MWT may not be feasible. Overall, these findings suggest a need to update the app and develop a more accurate process for measuring and interpreting the 6MWT before it can be used for clinical and research purposes. Our findings are particularly concerning given that younger university students are adept at using technology and applying simple standards for interpreting their results compared with older individuals living with or without chronic comorbidities [23].

Interestingly, our findings of inaccuracy are not consistent with those from a related study that tested an investigator-developed 6MWT app in older patients with chronic heart failure and hypertension [24]. The authors found that participants accurately and reliably measured the distance covered during the 6MWT using an app both within the laboratory and at home [24]. Participants in both studies reported that the apps were simple and easy to use independently [24]; however, the methods of measurement and app characteristics differed between the two studies and likely contributed to some of the inaccuracy observed in our study. Specifically, in the study by Brooks et al [24], participants were not required to count the number of laps walked or the distance between the starting point and endpoint of a single lap; the app did this for them and minimized the number of potential sources of measurement error. An advantage of the EasyMeasure app is that it is freely available to the public for download. However, the observed inaccuracy associated with our protocol using this technology solution negates the benefits of its accessibility. Furthermore, the age of the study participants was different. Older adults have less experience using technology and higher levels of technology-related anxiety than younger adults [23,25]. However, there is more research surrounding the needs of these individuals to successfully use technology in research and health care [23,25,26]. The younger participants in this study appeared to be quite comfortable using technology; however, this increased comfort with technology may have led to a decreased attention to the technology-related instructions provided and to the use of the various app settings in general [27].

The parallel form reliability findings revealed a significantly strong correlation between participants' self-administered 6MWT scores and assessor scores for the group using technology. However, the differences between participant and assessor scores all exceeded the MCID values for the 6MWT (ie, 19-49 m [10,11]). MCID is defined as the smallest difference in a score on an outcome where patients perceive a benefit and hence mandates a change in the patient's management [28]. The MCID was introduced to ensure that the outcomes of clinical trials were meaningful for the patient. In many instances, statistical significance is necessary but not sufficient [29]. As 6MWT MCID values were reached when comparing the differences between participant and assessor scores in all instances, concern arose as these differences could be interpreted as a meaningful difference to patients and affect the treatment they receive. Therefore, this result should be interpreted with caution.

Finally, validity results from this project found that 6MWT scores were significantly and strongly correlated with maximal treadmill test VT scores. This finding demonstrates that the 6MWT may be a valid measure of functional capacity and a marker of functional independence for clinicians to use when screening and monitoring patients in community settings. However, the results of this study showed that the 6MWT scores did not correlate with the maximal treadmill test VO_{2peak} scores. In this study, the 6MWT consistently underestimated VO_{2peak}. There is variability in the literature regarding this outcome, with some studies demonstrating the validity of the 6MWT in predicting VO_{2peak} [30,31] and others demonstrating that the

6MWT is not a valid test to predict VO_2peak [32]. This inconsistency is likely because the 2 tests measure different functional capabilities, and although the 6MWT may require near-maximal effort in some frail or impaired populations, it is not a valid measure of maximal oxygen uptake in many populations. Owing to the variability in correlation outcomes, it may be worthwhile to explore the use of other tests that could be self-administered to use as a predictor of functional capacity. For example, the Siconolfi step test [33] is a test in which participants are required to step up and down from a 10-inch step for a maximum of three 3-minute stages with increasing step rates [33]. It is a test that can be performed in any setting and is validated to predict VO_{2peak} in healthy adults [34,35] and those with a variety of chronic conditions [33,36,37]. Future studies should look at the potential of having this test be self-administered and compare different formats of functional capacity tests to determine which is most accurate and which participants are most satisfied with. Furthermore, more research is needed to test the effects of autonomously implemented functional capacity tests in older adults. A systematic review examining the use of mobile phones for health in older adults found 21 studies using distance-based interventions, and none of the programs included functional capacity assessment [38]. The concern is that interventions are delivered without appropriate baseline assessments or clearance.

Future Research

On the basis of the findings of this study, it is recommended that the app used to self-administer the 6MWT be redesigned. Future apps should include functions that count laps, measure total distance walked, and time the test for users. This would help to overcome participant errors demonstrated in this study because of difficulty counting test laps and miscalculation of the total distance walked. In addition, several modifications to our tested methods should be considered to help overcome the usability issues identified in this study. The primary recommendation is to provide more detailed information and education to participants regarding the methods needed to accurately perform the test. This should include training videos or written instructions in addition to verbal instructions on how to calibrate the app to accurately measure the distance walked and information on how to perform and score the test. This would allow participants to review instructions before beginning the test, which may be most important if the test is being used with older adults or individuals who report a lack of competence with new technologies [38,39]. Other recommendations include allowing participants to have a *training run* before fully scoring the test and obtaining verbal feedback on performance for the first test, which could be completed virtually by a health care professional trained in scoring the test. The verbal feedback and encouragement given to the participants in the standard 6MWT group may have motivated them to walk faster and achieve a higher 6MWT score compared with participants in the technology group who did not have the same encouragement [40]. A *training run* may also serve to provide motivation and encouragement in the future.

Limitations

The results of this study should be viewed with an understanding of their limitations. Testing of the self-administered 6MWT, which was designed to mimic a home-based test, took place in a laboratory setting. Although these tests were implemented in a room that was roughly the size of a large living room, we recognize that this does not reflect the space available to many people and suggest adding a third home-based arm in future studies. Adding a third home-based arm would be ideal because it would allow researchers to differentiate between issues resulting from measurement tools and measurement settings. In addition, the small sample size was determined based on usability study recommendations, and a larger sample with more diverse characteristics should be used for future testing and power considerations. A limitation of the 6MWT is evidence of a ceiling effect [41]; therefore, it is thought to be a more useful measure in older, deconditioned individuals than in young able-bodied populations.

Conclusions

In conclusion, this study demonstrated significant usability concerns regarding the accuracy of a self-administered 6MWT using the EasyMeasure app. Despite the reported ease of use of this technology, the inaccurate measurements and challenges associated with interpreting the test scores suggest that the app design and tested protocol are of limited use for research and clinical purposes. However, the strong and significant correlation between the 6MWT and VT values demonstrates the potential of the 6MWT to measure functional capacity for community-based exercise screening and patient monitoring. Further research is needed to develop a more accurate means of implementing and interpreting a self-administered 6MWT to facilitate pre-exercise screening and patient assessment for distance-based health care and research purposes.

Conflicts of Interest

None declared.

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Abbreviations

6MWT: 6-minute walk test
CPET: cardiopulmonary exercise test
MCID: mean clinically important difference
RPE: rate of perceived exertion
UTAUT: Unified Theory of Acceptance and Use of Technology
VO2peak: peak oxygen uptake
VT: ventilatory threshold

Original Paper

Digital Rehabilitation for Acute Ankle Sprains: Prospective Longitudinal Cohort Study

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Abstract

Background: Ankle sprains are one of the most prevalent soft-tissue injuries worldwide. Physical therapy, especially progressive exercise, has proven effective in improving function, while preventing recurrence.

Objective: We aim to present the results of a fully remote and digitally guided rehabilitation program for acute ankle sprains.

Methods: We performed a prospective longitudinal cohort study of individuals eligible for workers' compensation, who were referred for digital rehabilitation therapy for a sprained ankle. Therapeutic exercise sessions were to be performed independently by the patient at home using the biofeedback device provided by SWORD Health. Primary endpoints were the change in self-reported Numerical Pain Rating Scale (NPRS) and Foot and Ankle Ability Measure–activities of daily living (FAAM–ADL) and FAAM–Sports scores. Participants were assessed at baseline, end of the program, and 6 months after program completion. Secondary outcomes included digital therapy dosage, pain and fatigue during sessions, and satisfaction.

Results: In total, 93 (89.4%) patients completed the program and 79 (76.0%) were available for follow-up. Changes in the primary outcomes between baseline and the 6-month follow-up were both significant ($P<.001$) and clinically meaningful: mean difference of –2.72 points (95% CI –3.31 to –2.13) on the NPRS (49.8% reduction), 21.7 points (95% CI 17.13-26.27) on the FAAM–ADL (41.1% increase), and 37.8 points (95% CI 30.45-45.15) on the FAAM-Sports (151.8% increase). Longer waiting periods between the accident date and treatment initiation were found to negatively impact functional status at baseline and at the end of the program, triggering an extension in the program duration. The total training volume (12.5 hours, SD 10.5 hours) was similar to that of other interventions for ankle sprains, but the dosage per week was much higher (2.4 hours per week, SD 0.87 hours per week). The mean patient satisfaction score was 8.8 (SD 1.57) out of 10. Among program completers, 83.9% attained full recovery and were discharged with no residual disability.

Conclusions: Being far less demanding in terms of human resources, the digital program presented constituted a viable, clinically effective, and convenient solution for ankle sprain rehabilitation, particularly during the pandemic. This is the first study presenting a fully remote home-based rehabilitation program for acute ankle sprains, with patients achieving sustained long-term results. This was a prospective cohort study and, as such, did not include a control group, but the results appear comparable to those published for face-to-face interventions.

Trial Registration: ClinicalTrials.gov NCT04819022; https://clinicaltrials.gov/ct2/show/NCT04819022

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Introduction

Ankle sprains are one of the most prevalent soft-tissue injuries, with an estimated incidence of 2.15 per 1000 person-years in the United States [1] and 5-7 per 1000 person-years in Europe [2]. They are more common in the second and third decades of life [3], but only about half are associated with sports participation, suggesting that they may affect individuals with different physical activity levels [1].

Given their high incidence, ankle sprains have an important socioeconomic impact, mainly from indirect costs [4,5]. Overall costs range from US $1809-$5271 per patient, with direct costs representing US $292-$2268 [6]. Other studies estimate that indirect costs make up for 70%-90% of the total costs [5,7].

It has also been observed that 12%-47% of all ankle sprains are recurrent [8-12], and at least one-third of individuals experience residual symptoms [13-15]. In fact, evidence suggests that individuals with previous ankle sprain are at an approximately 3.5 times greater risk of recurrence [1], and that up to 45% of patients report an incomplete recovery 3 years after injury [16].

Ensuring complete recovery and a decreased risk of reinjury are therefore of paramount importance. Physical therapy, especially progressive exercise, has been shown to not only improve function [17-23] but also prevent recurrence [17,24,25]. Effectiveness seems to improve with intensity, especially in doses of more than 900 minutes of total exercise time [18].

Notwithstanding, access to physical therapy interventions remains a challenge, owing to physical mobility and transportation limitations [26-29]. Home-based interventions have been studied as alternatives. However, despite being associated with improved outcomes [30], a systematic review reported diminished gains in pain and physical capacities when compared to supervised rehabilitation [31]. Additionally, low compliance is a known issue [32].

A potential solution is telerehabilitation, which helps alleviate time, travel, and access barriers, while potentiating intensity and satisfaction [33-36]. Another advantage of telerehabilitation is the minimal person-to-person contact, which is particularly relevant in the actual pandemic context. Indeed, there is growing research on its application in a variety of musculoskeletal conditions [33,34,37-39], with promising results in comparison with conventional care [35,40]. Studies have also demonstrated that remote patient assessment is technically feasible and valid for ankle joint disorders [36]. However, there is still a lack of adoption of telerehabilitation [41] as well as intrinsic limitations regarding access to technology and the need for real-time availability of a physical therapist.

To overcome this limitation, technological approaches allowing independent home-based rehabilitation have been developed, but these are still experimental, and clinical validation is scant [42]. In previous clinical studies, we demonstrated the feasibility and safety of digitally delivered rehabilitation programs after total knee and hip replacement [43-45], as well as the ability to maximize clinical outcomes over conventional physical therapy through the same technology.

New digital programs aimed at treating other conditions have since been developed. This paper presents the results of a prospective, consecutive cohort of patients undergoing a fully remote rehabilitation program for acute ankle sprain.

Methods

Study Design

This is a prospective, longitudinal cohort study aimed to assess the clinical outcomes of digital rehabilitation programs provided by SWORD Health.

Participants

Individuals eligible for workers' compensation under health plans, which have entered into a commercial agreement with SWORD Health, acting as an in-network provider of physical therapy services, were recruited. Patients were initially assessed by their orthopedic surgeon and referred for physical therapy after confirmation of an ankle sprain (based on clinical and imaging findings). Referral to in-network providers of physical therapy was managed administratively, with the possibility of explicit referral to the digital program by the orthopedic surgeon.

Rehabilitation Program

The plan of care was based on therapeutic exercise sessions to be performed independently by the patient at home using the biofeedback device provided by SWORD Health, in accordance with the protocol presented in Multimedia Appendix 1. Patients were instructed to perform 1 exercise session per day. The plan was adapted by the treating physician in articulation with the physical therapist as needed. Program duration and patient discharge were determined by the treating physician.

Study Outcomes

The primary outcome was the change in the self-reported Numerical Pain Rating Scale (NPRS) score (0-10), as well as the change in the Foot and Ankle Ability Measure (FAAM) [46]—for activities of daily living (FAAM–ADL) and sports (FAAM–Sports) between baseline and the 6-month follow-up. Patients were assessed for these outcomes at baseline, end of the rehabilitation program, and at 6 months, through an electronic survey. The NPRS was self-reported at each assessment survey with the question, "How would you rate your pain over the last 7 days – from 0 (no pain at all) to 10 (worst pain imaginable)?"

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Secondary outcomes included the following user experience–related outcomes, collected along the program by the digital therapist:

1. Treatment dosage: program duration (days), number of sessions per week, total number of sessions, minutes per session, and total exercising time (minutes and hours).
2. Average pain during sessions: self-reported at the end of each session; visual analogue scale (VAS) scores of 0-10;
3. Change in pain during sessions: last versus first VAS score for pain registered;
4. Average fatigue during sessions: self-reported at the end of each session; VAS scores of 0-10;
5. Change in fatigue during sessions: last versus first VAS score for fatigue registered;
6. Satisfaction: assessed at the end of the program with the question, "On a scale from 0 to 10, how likely is it that you would recommend this intervention to a friend or neighbor?"

Statistical Analysis

To assess differences in primary and secondary outcomes among the 3 time points, a Bonferroni multiple comparison test was performed with time as a categorical variable. Both unadjusted and adjusted differences for covariates with 95% CIs were estimated. Included covariates were age, gender, BMI, days to start treatment, grade of sprain, exercise level, and previous injury.

Linear mixed-effects models (LMM) were also utilized to assess participant change across NPRS, FAAM–ADL, and FAAM–Sports metrics from baseline to the end of the study. This type of model was chosen over a repeated-measures analysis of variance (ANOVA) since the former allows for a relaxation of model assumptions (ie, it does not assume that variances and covariances among groups are equal), a more flexible treatment of time (which is treated as a continuous variable and not a category), and makes it easier to include covariates (as additional fixed-effects) [47].

For each outcome, a model was created without including covariates (unadjusted) and including covariates (adjusted). Multiple imputation using 50 imputed data sets was used to account for attrition in each variable across time [48].

A bivariate correlation analysis was also performed to investigate covariates' association with outcomes.

A repeated-measures ANOVA was also performed for the primary outcomes with time as the within-subjects factor and grade of sprain (grades I-III per the guidelines of Lynch [49]) as the between-subjects factor. The same approach was used with program duration categories (<4 weeks and >4 weeks) as the between-subjects factor.

LMM analysis was performed using R. All the other statistical analyses were performed using SPSS (version 17.0; SPSS Inc).

Data Availability

Deidentified individual participant data are provided in Multimedia Appendix 2.

Results

Baseline Characteristics of Participants

In total, 104 patients from 4 different recruitment sites and 26 different orthopedic surgeons were consecutively enrolled in SWORD Health's fully remote physical therapy program for ankle sprain between February and November 2020 (Figure 1). The dropout rate was 10.6% (11/104); 1 (1.0%) patient subsequently refused all types of care proposed by the physician, 5 (4.8%) dropped out owing to unknown reasons (missing exercise sessions and medical appointments), and 5 (4.8%) did not adhere to the digital program. In total, 93 (89.4%) patients completed the program, and 79 (76.0%) were available for follow-up.

Participant's baseline characteristics are presented in Table 1. Baseline assessment of the outcome variables is summarized in Table 2.

Figure 1. Flow chart for participant inclusion (left) and attrition (right). FAAM–ADL: Foot and Ankle Ability Measure–activities of daily living, FAAM–Sports: Foot and Ankle Ability Measure–sports, NPRS: Numerical Pain Rating Scale.
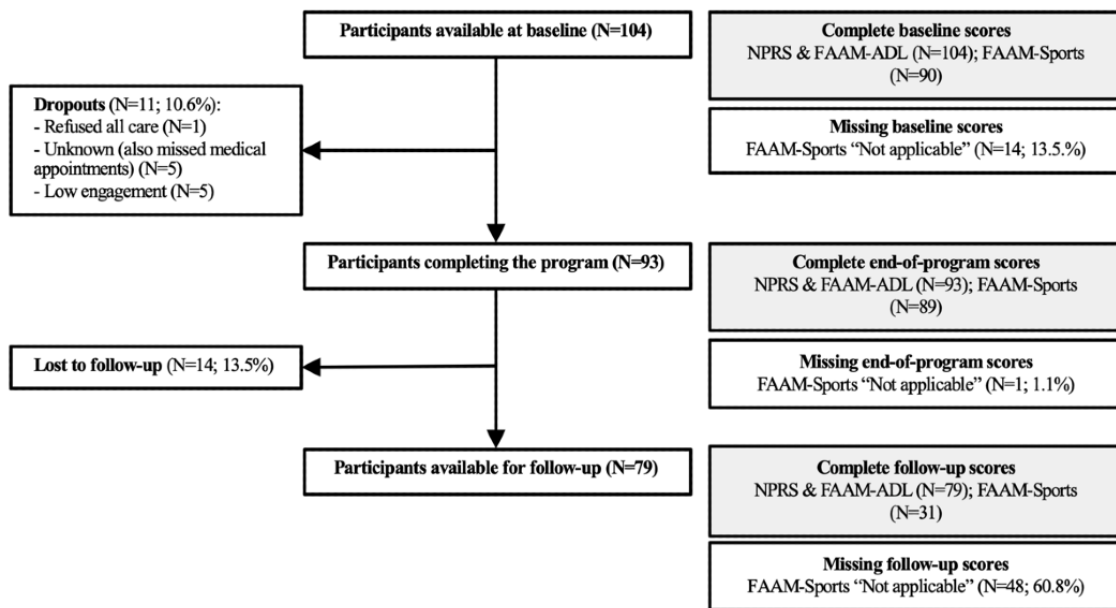
Table 1. Baseline characteristics of participants who finished the rehabilitation program (N=93).

Characteristic	Value
Age (years), mean (SD)	40.7 (10.43)
Age (years), n (%)	
<25	9 (9.7)
25-40	36 (38.7)
>40	48 (51.6)
Females, n (%)	50 (53.8)
BMI, mean (SD)	27.8 (4.98)
BMI categories, n (%)	
Underweight (<18.5)	0 (0)
Normal (18.5-25)	32 (34.4)
Overweight (25-30)	32 (34.4)
Obese (>30)	29 (31.2)
Affected side: right, n (%)	47 (50.5)
Grade of ankle sprain, n (%)[a]	
I	53 (57.0)
II	27 (29.0)
III	10 (10.8)
Exercise level (hours per week), n (%)	
0	36 (38.7)
1-2	30 (32.3)
3-4	16 (17.2)
≥5	11 (11.8)
Previous injury, n (%)	27 (29)
Previous surgery, n (%)	0
Time from injury date to treatment initiation (days), mean (SD)	53.2 (48.26)
Time from referral to SWORD and treatment initiation (days), mean (SD)	3.8 (2.17)

[a]Three observations are missing.

Table 2. Estimates for patient-reported outcomes at baseline, end of the program, and 6-month follow-up assessment, unadjusted and adjusted for covariates.

Time	Unadjusted for covariates, mean (95% CI)	Adjusted for covariates[a], mean (95% CI)
Numerical Pain Rating Scale score		
Baseline	5.67 (5.16-6.17)	5.46 (4.86-6.05)
End of program	3.67 (3.16-4.17)	3.46 (2.87-4.06)
6-month follow-up	2.92 (2.42-3.43)	2.73 (2.15-3.32)
Foot and Ankle Ability Measure–activities of daily living score		
Baseline	52.00 (47.90-56.10)	52.70 (47.80-57.60)
End of program	63.50 (59.50-67.60)	64.30 (59.50-69.20)
6-month follow-up	73.50 (69.50-74.40)	74.40 (69.60-79.20)
Foot and Ankle Ability Measure–sports score		
Baseline	26.70 (20.40-32.90)	24.90 (17.40-32.40)
End of program	46.20 (39.90-52.40)	44.60 (37.20-52.00)
6-month follow-up	64.30 (58.00-70.50)	62.70 (55.30-70.10)
Visual analogue scale for pain score (0-10)		
Baseline	3.98 (3.56-4.40)	3.52 (2.74-4.30)
End of program	2.84 (2.37-3.31)	2.36 (1.88-2.85)
Visual analogue scale for fatigue score (0-10)		
Baseline	2.73 (2.30-3.17)	2.08 (1.29-2.87)
End of program	2.77 (2.25-3.30)	2.15 (1.61-2.69)

[a]Adjusted for age, gender, BMI, days to start treatment, grade of sprain, exercise level, and previous injury.

Longitudinal Changes in Outcomes

Table 2 presents the primary and secondary clinical outcomes. All patients showed significant improvement in NPRS, FAAM–ADL, FAAM–Sports, and VAS pain scores ($P<.001$) from baseline to 6-month follow-up (Table 3).

Essentially, considering the minimal clinically important difference values established for FAAM subscales [50] (ie, 8 points for FAAM–ADL and 9 points for FAAM–Sports), the registered changes from baseline were also clinically meaningful. Overall, patients experienced reductions of 50% and 33% in the NPRS and VAS pain scores, respectively, which can also be considered clinically significant.

Table 3. Differences in adjusted[a] estimates upon multiple comparison at different time points assessed for the primary endpoints, pain, and fatigue sessions.

| Time-point comparisons	Estimate difference (95% CI)	SE	t test (df)	Bonferroni P value
Numerical Pain Rating Scale score				
End of program vs baseline	–1.99 (–2.58 to –1.40)	0.30	–6.63 (184)	<.001[b]
6-month follow-up vs baseline	–2.72 (–3.31 to –2.13)	0.30	–9.04 (184)	<.001[b]
6-month follow-up vs end of program	–0.73 (–1.32 to –0.14)	0.30	–2.42 (184)	.05[b]
Foot and Ankle Ability Measure–activities of daily living score				
End of program vs baseline	11.60 (7.03 to 16.17)	2.33	5.00 (184)	<.001[b]
6-month follow-up vs baseline	21.70 (17.13 to 26.27)	2.33	9.31 (184)	<.001[b]
6-month follow-up vs end of program	10.00 (5.43 to 14.57)	2.33	4.31 (184)	<.001[b]
Foot and Ankle Ability Measure–sports score				
End of program vs baseline	19.70 (12.37 to 27.03)	3.74	5.26 (184)	<.001[b]
6-month follow-up vs baseline	37.80 (30.45 to 45.15)	3.75	10.10 (184)	<.001[b]
6-month follow-up vs end of program	18.10 (10.77 to 25.43)	3.74	4.84 (184)	<.001[b]
Visual analogue scale for pain score (0-10)				
End of program vs baseline	–1.16 (–1.64 to –0.67)	0.24	–4.72 (89)	<.001[b]
Visual analogue scale for fatigue score (0-10)				
End of program vs baseline	0.07 (–0.47 to 0.61)	0.28	0.24 (89)	.81

[a]Adjusted for age, gender, BMI, days to start treatment, grade of sprain, exercise level, and previous injury.

[b]Statistically significant at $P<.05$.

LMM analysis with 50 imputed data sets revealed that for all unadjusted models, significant effects of time were observed in the expected directions. This indicates that over the larger study timeline, participants reported significant improvements in NPRS, FAAM–ADL, or FAAM–Sports scores (Multimedia Appendix 3). Longitudinal changes in ankle function and pain perception are depicted in Figure 2.

Figure 2. Linear mixed model showing the individual and aggregate longitudinal changes in the primary endpoints (FAAM–ADL, FAAM–Sports, and NPRS scores). Each thin line represents a participant, and the thick dotted line represents the average change across all participants. Covariates appearing in the model include age, gender, BMI, days to start treatment, grade of sprain, exercise level, and previous injury. Significant effects were found for covariates (P<.05). FAAM–ADL: Foot and Ankle Ability Measure–activities of daily living, FAAM–Sports: Foot and Ankle Ability Measure–sports, NPRS: Numerical Pain Rating Scale.
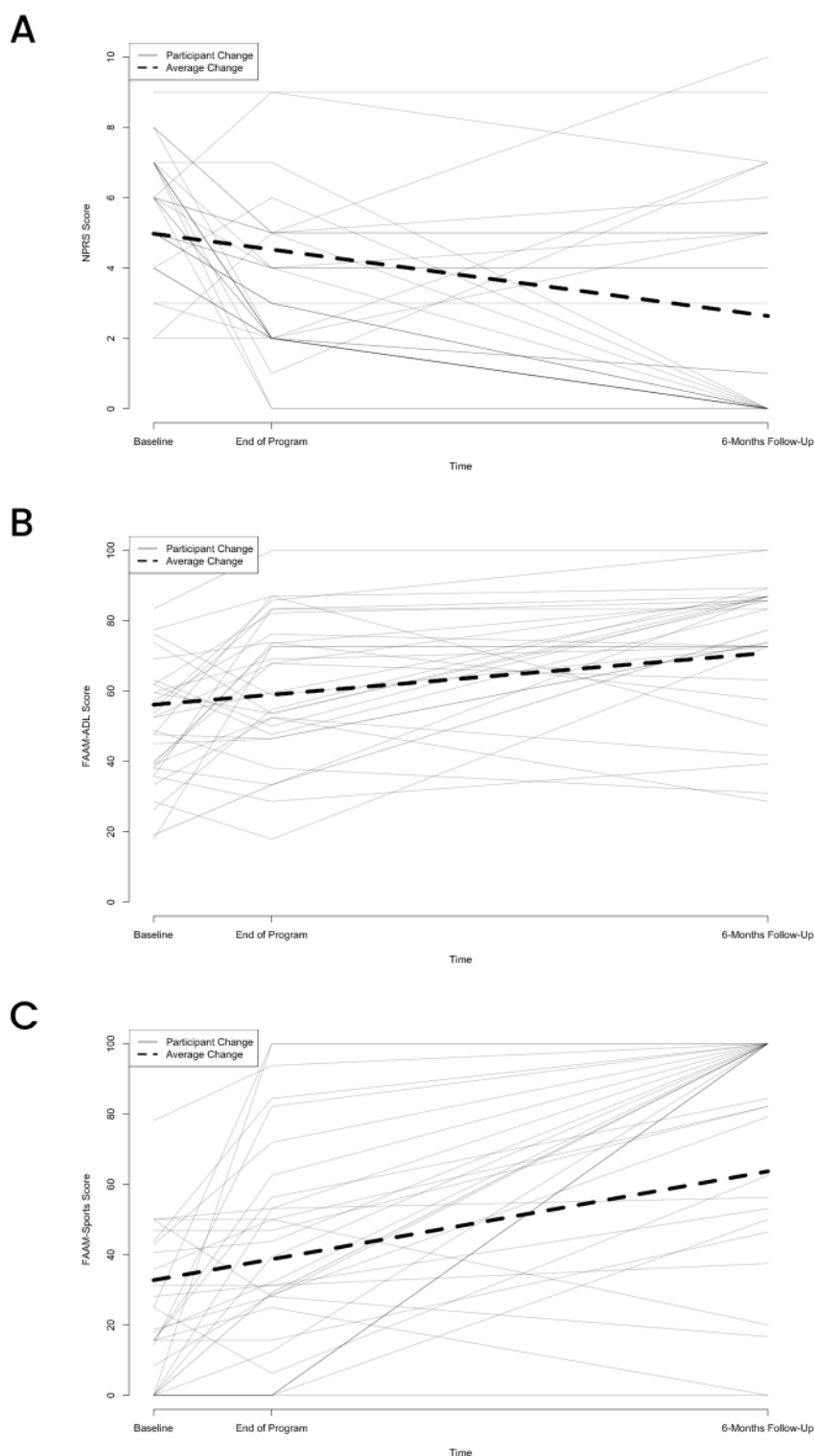
Similar effects of time were found for all adjusted models (Multimedia Appendix 3). Regarding NPRS scores, participants with a higher average BMI (estimate=0.08; P=.04) and those who took days to start treatment (estimate=0.01; P=.02) had significantly higher scores. A significant negative linear effect of sprain grade was also observed (estimate=–1.00; P=.02). No covariates significantly affected FAAM–ADL scores. Regarding FAAM–Sports scores, older participants showed significantly lower scores (estimate=0.58; P=.03). A significant negative quadratic effect of sprain grade was also observed (estimate=0.01; P=.02).

Usability-Related Outcomes

Compliance and Training Intensity

Program completers performed on average 5.9 (SD 1.34, range 0.9-7.8) sessions per week (Table 4), with 39.8% (37/93) of them performing 7 sessions per week, 45.2% (42/93) performing 5-6 sessions per week, and 15% (14/93) performing less than 5 sessions per week. The mean program duration was 5.0 (SD 3.81, range 0.9-19.6) weeks, and the mean total exercise dosage was 750.6 (SD 630.25, range 77.1-2836.4) minutes, with 30% (28/93) of patients executing more than 900 minutes of exercise

therapy, a threshold that has been described as being associated with better outcomes [18]. No significant correlation was found between total exercising time and primary endpoints.

Session-Related Pain and Fatigue

On their last session, patients reported significantly lesser pain than the initial session ($P<.001$). Patient-reported fatigue did not change ($P=.81$; Table 3), which reflects progression of session intensity/difficulty over time. Mean values for VAS pain and VAS fatigue scores during exercise sessions are presented in Table 4.

Table 4. System usability–related outcomes for patients who finished the rehabilitation program (N=87).

Usability outcomes	Measure	
	Mean (SD)	Range
Program duration (weeks)	5.0 (3.81)	0.9-19.6
Sessions per week	5.9 (1.34)	0.9-7.8
Total number of sessions	28.9 (21.99)	3-115
Total exercising time (min)	750.6 (630.25)	77.1-2836.4
Total exercising time (hours)	12.5 (10.50)	1.3-47.3
Minutes per session	24.7 (5.86)	12.0-37.2
Average pain during sessions (visual analogue scale for pain score, 0-10)	3.5 (1.45)	0 -7.7
Average fatigue during sessions (visual analogue scale for fatigue score, 0-10)	3.1 (1.66)	0-6.8
Satisfaction (0-10)[a]	8.8 (1.57)	4-10

[a]Two observations are missing.

Satisfaction

The mean satisfaction score was 8.8 (SD 1.57, range 4-10) points (Table 4). In total, 63.4% (59/93) of patients answered "9" or "10," 23.7% (22/93) answered between "7" and "8," and 10.7% (10/93) answered "6" or less.

Disability and Return to Work

Among those who finished the program, 83.9% (78/93) of patients were classified by the treating physician as having obtained maximum medical improvement and no residual disability, while 12 (13%) patients were rendered with permanent partial disability, 2 (2%) with temporary total disability, and 1 (1%) with permanent total disability.

In total, 48.4% (45/93) of completers returned to work before clinical discharge. Within those discharged with no residual disability, the majority (53.8%, 42/78) did not return to work before clinical discharge, likely because of the shorter treatment period (median 2.8 weeks, IQR 4.04 weeks; range 0.86-9.57 weeks).

Reinjury and Adverse Events

The reinjury rate was 2.5%; 2 of the 79 available patients for follow-up reported ankle sprain recurrence as a result of a fall. One was a patient who had had 4 previous ankle sprains, and the other did not have a history of previous injury. Both had been discharged with no residual disability.

The adverse event rate was 3.2% (Multimedia Appendix 4). One patient reported exacerbated ankle pain caused by long walks; one could not perform the sessions due to a suspected plantar fasciitis; and another reported intense lower back pain, limiting compliance with the exercise protocol. None were related to the digital intervention.

Subgroup Analysis

Grade of Ankle Sprain

This analysis confirmed a main effect of time for the 3 dimensions of NPRS ($P=.05$) and FAAM–ADL ($P=.003$) after 6 months. The results are presented in Tables 5 and 6 and Figure 3.

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Table 5. Repeated-measures analysis of variance for the primary outcomes based on the grade of sprain.

Outcome variable	Grade of sprain					
	Time		Sprain grade		Time × sprain grade	
	F test (df1, df2)	P value	F test (df1, df2)	P value	F test (df1, df2)	P value
Numerical Pain Rating Scale score	3.30 (1.77, 123.74)	.05	2.22 (2, 70)	.12	1.22 (3.54, 123.74)	.31
Foot and Ankle Ability Measure–activities of daily living score	6.15 (1.90, 133.21)	.003	0.91 (2, 70)	.41	1.84 (3.81, 133.21)	.13
Numerical Pain Rating Scale score	4.58 (1, 83)	.03	3.63 (2, 83)	.03	4.15 (2, 83)	.02

Table 6. Repeated-measures analysis of variance for the primary outcomes based on the duration of the program.

Outcome variable	Program duration					
	Time		Program duration		Time × program duration	
	F test (df1, df2)	P value	F test (df1, df2)	P value	F test (df1, df2)	P value
Numerical Pain Rating Scale score	2.31 (1.80, 126.07)	.11	3.03 (1, 70)	.09	0.98 (1.80, 126.07)	.37
Foot and Ankle Ability Measure–activities of daily living score	3.70 (1.89, 131.98)	.03	7.62 (1, 70)	.01	0.50 (1.88, 131.98)	.60
Numerical Pain Rating Scale score	3.97 (1, 83)	.05	1.43 (1, 83)	.24	2.16 (1, 83)	.14

Overall, patients with sprain grade II experienced the greatest improvement, with outcomes converging in the long term.

Regarding FAAM–Sports scores, it was not possible to account for the 6-month follow-up in the repeated-measures analysis, since 60.8% (48/79) of answers to the FAMM–Sports questionnaire were not applicable during the pandemic period, yielding a very small sample size per subgroup (n=18, 10, and 3 for sprain grades I, II, and III, respectively). Outcomes following the end of the program for this dimension revealed a main effect of time (P=.05) and grade of sprain (P=.03) and an interaction between time and grade of sprain (P=.02). Differences among the 3 subgroups were detected at the end of the program (P=.01, 1-way ANOVA), with post hoc multiple comparisons showing that patients with grade II sprain scored significantly higher than those with grade III sprain (P=.01; mean difference 34.1 points, 95% CI 6.28-61.94 points).

Figure 3. Estimated marginal means over time based on (A) sprain grade I, II , and III for NPRS and FAAM–ADL scores (n=45, 23, and 9, respectively; baseline to 6-month follow-up) and for FAAM–Sports (n=47, 24, and 7, respectively; baseline to the end of the program) and (B) program duration up to 4 weeks and above 4 weeks for NPRS and FASAM–ADL scores (n=39 and 38, respectively; baseline to 6-month follow-up), and for FAAM–Sports (n=41 and 37, respectively; baseline to the end of the program). FAAM–ADL: Foot and Ankle Ability Measure–activities of daily living, FAAM–Sports: Foot and Ankle Ability Measure–sports, NPRS: Numerical Pain Rating Scale.
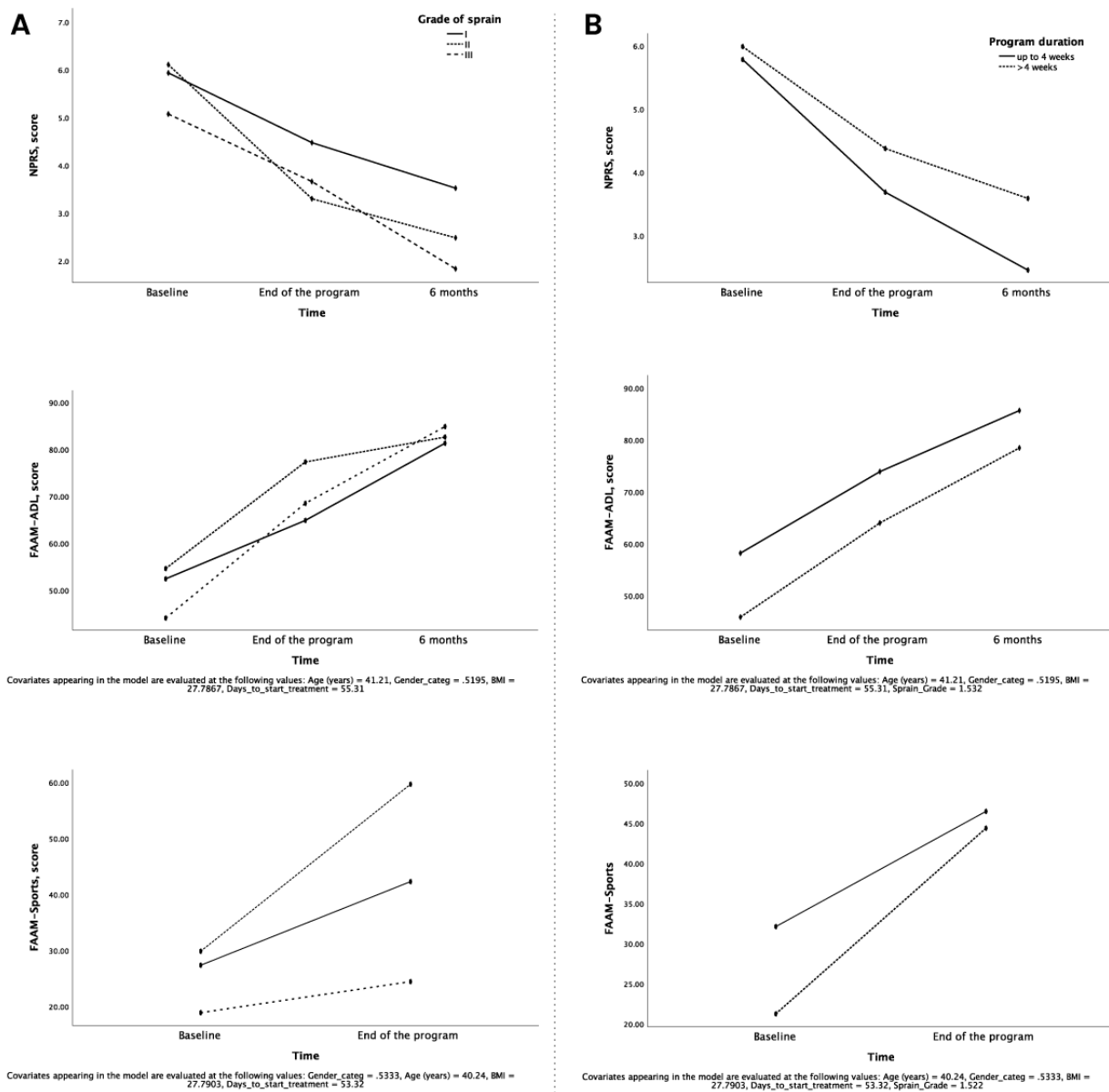
Program Duration

The mean program duration was 5.0 (SD 3.81, range 0.9-19.9; median 4.1, IQR 5.0; 95% CI 4.3-5.8) weeks, with over half of the sample (54.8%, 51/93) discharged within 4 weeks. Hence, a cut-off of 4 weeks was established to explore differences in outcomes between patients discharged before or after that cut-off.

This analysis confirmed a main effect of time and program duration for FAAM–ADL after 6 months (P=.03 and P=.01, respectively). An effect of time was also observed on FAAM–Sports (P=.05) between baseline and the end of the program. No other effects or interactions were detected (Table 5 and Figure 3).

Patients requiring >4 weeks of treatment had significantly worse baseline and end-of-program FAAM–ADL scores (P=.002 and P=.02, respectively; independent samples t test). NPRS was not different at baseline (P=.76), but patients in the <4 weeks group reported less pain at the 6-month follow-up assessment (P=.05; independent samples t test) along with better functional outcomes (P=.03 for FAAM–ADL; independent samples t test). FAMM–Sports scores were also not different at baseline (P=.05; independent samples t test), and patients in both subgroups recovered similarly for this dimension.

Discussion

Principal Findings

This study shows that a fully remote, home-based, digital rehabilitation program for acute ankle sprains delivered at patients' homes allowed patients to attain clinically meaningful improvement in pain (evident from their VAS and NPRS scores), activities of daily living (FAAM–ADL scores), and sports activities (FAAM–Sports scores). Furthermore, these programs led to a full recovery without residual disability in 83.9% of patients, which compares favorably with the published literature showing that at least one-third of individuals will experience residual symptoms [13-15].

There is a dearth of studies on digital programs for acute ankle sprains, as supported by recently published systematic [51] and literature [52] reviews on the subject. We therefore broadened the search to include exercise-based approaches in general [23,53-55]. Overall, the results obtained in this study are similar to those reported for other supervised exercise programs, and the first detailed positive outcomes with a fully digital program.

One RCT (n=90) [55] assessed the effectiveness of exercise training using the Nintendo Wii Fit balance board in comparison to physical therapy and to a control receiving no therapy. Investigators found this tool was not more effective than PT only or no exercise. Of note, patients enrolled in this study had little room left for improvement, with near-normal scores at baseline on the FAAM–ADL (mean 71-83) and FAAM–Sports (mean 37-52), and low VAS pain (approximately mean 1 point), which may have been the reason behind no difference between physical therapy only or no exercise.

In another RCT (n=74) [54] comparing an manual therapy and exercise (MTEX) program with a home exercise program (HEP), the improvement in the MTEX program at 4 weeks was similar to what we observed in this study: FAAM–ADL score, mean 21.3 (95% CI 18.2-24.5) points; FAAM–Sports score, mean 27.1 (95% CI 22.7-31.6) points; and NPRS score, mean –2.7 (95% CI –2.9 to –2.5) points. When compared to the HEP group, our intervention also provided superior outcomes in terms of functional recovery and pain.

Both NPRS baseline values and its magnitude of change from baseline to the end of the program were similar to the ones reported for other exercise interventions after ankle sprain [23,54,56].

Recurrence and Completeness of Recovery

This study corroborates previous findings of high recurrence rates both among nonathlete (24%-54%) [57,58] and athlete (12%-47%) populations, with 29% of all enrolled patients having had previous injury.

Also consistent with our findings, the group from Verhagen found that a home-based proprioceptive 8-week training program, delivered through a mobile app after usual care, was successful in reducing recurrences of ankle sprains in a 12-month period as against conventional care alone (22% versus 33%, as revealed through an RCT with 522 athletes from the Netherlands) [59]. Although the rate of reinjury was still much

higher than that reported here at 6 months (2.5%), this further supports the effectiveness of remote interventions in preventing ankle reinjuries.

Previous findings indicate an association between the rate of resprain and incomplete recovery [57]. Therefore, the high percentage of complete recovery attained in this study may explain the lower rate of recurrence, even if the 2 patients who experienced recurrence had been discharged with no residual disability. In fact, by the 6-month follow-up, 45.6% (36/79) and 35.5% (11/31) of patients in this study, respectively, achieved scores compatible with the normative values for FAAM–ADL and FAAM–Sports reported for the adult population (92.3 and 85.1 points, respectively) [60].

Training Volume

In a systematic review and meta-analysis, Bleakley et al [61] found no clear consensus on an optimal training volume, with rehabilitation times ranging from 3.5 to 21 hours (median 12 hours). The highest total rehabilitation time was 21 hours, equivalent to 1.75 hours per week over 12 weeks. In our study, the mean total exercising time was 12.5 (SD 10.50, range 1.3-47.3) hours, equivalent to 2.4 (SD 0.87, range 0.4-4.6) hours per week. Hence, the total training volume was similar to that of other interventions, but dosage per week was much higher.

Subgroup Outcomes

Even though overall changes from baseline to follow-up were not significantly different between patients discharged before or after 4 weeks (no interaction found between time and program duration), the latter patients had worse FAAM–ADL scores both prior to participating in the program and at discharge, and worse NPRS and FAAM–ADL scores at 6 months.

We hypothesize this could be a consequence of the particularly long period between the injury date and treatment initiation—mean 53.2 (SD 48.26, range 4-281) days—mainly in relation to disruptions in health care delivery in the wake of the COVID-19 pandemic. (ie, a delay between injury and the physician appointment) (Table 1). Indeed, we found a correlation between longer waiting periods and extended program duration (Pearson r_{93}=0.48; P<.001), with mean waiting times of 40.9 (SD 38.79) days for patients who were discharged within 4 weeks versus 68.1 (SD 54.57) days for those discharged after 4 weeks (P=.01).

Recent reviews have not found sufficient evidence regarding independent predictors of clinical outcomes [62,63]. Only 1 study so far gathered proof that a low injury grade is a predictor for better outcomes [64].

In this study, no differences were found in terms of program duration between injury grades (P=.11, 1-way ANOVA; grade I: 4.8 weeks, 95% CI 3.8-5.8 weeks; grade II: 4.7 weeks, 95% CI 3.2-6.2 weeks; grade III: 7.5 weeks, 95% CI 3.7-11.2 weeks). Nonetheless, we found differences between injury grade and clinical improvement. Patients with grade II injuries experienced the greatest improvement during the program, followed by those with grade I and then grade III injuries. This could be explained by the fact that grade I sprains are only directed to physical therapy in case of aggravation, at a point where they actually

become slower respondents. In the long term, however, patients with grade III sprain reported the greatest improvement in NPRS and FAAM–Sports scores, followed by those with grade II and grade I sprain, as confirmed by LMM analysis. This is most likely related to the lower FAAM scores and higher pain levels at baseline in patients with grade III sprain, consequently with a higher margin of progression. These aspects, along with the convergence of clinical outcomes over time for the 3 groups, do not support the notion of a low injury grade being a predictor for better outcomes.

Limitations

The limitations of this study are mainly related to the study design and the referral process. This was a prospective cohort study and, as such, did not include a control group. However, as shown above, our results are comparable to those reported previously for supervised exercise programs in this same context. Regarding the referral process, while patient assignment to an in-network provider was largely performed administratively, explicit referral to digital programs was possible. This may have introduced a selection bias toward patients more likely to engage in digital care.

Conclusions

This was the first study presenting the outcomes from a fully remote exercise-based rehabilitation program for acute ankle sprains, demonstrating clinically meaningful change in both pain and function, as well as complete recovery in 81.7% of patients, with sustained results over time. As such, this study demonstrates not only the feasibility of fully digital programs in this context, but also that these programs can achieve clinical outcomes comparable to face-to-face interventions.

Multimedia Appendix 1
Fully remote rehabilitation protocol applied for acute ankle sprains.
[DOCX File , 16 KB - rehab_v8i3e31247_app1.docx]

Multimedia Appendix 2
De-identified participants data.
[XLSX File (Microsoft Excel File), 50 KB - rehab_v8i3e31247_app2.xlsx]

Multimedia Appendix 3
Support statistical analysis tables.
[DOCX File , 25 KB - rehab_v8i3e31247_app3.docx]

Multimedia Appendix 4
Adverse events list.
[DOCX File , 13 KB - rehab_v8i3e31247_app4.docx]

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Abbreviations

ANOVA: analysis of variance
FAAM–ADL: Foot and Ankle Ability Measure–activities of daily living
FAAM–Sports: Foot and Ankle Ability Measure–sports
HEP: home exercise program
LMM: linear mixed-effects model
MTEX: manual therapy and exercise
NPRS: Numerical Pain Rating Scale

RCT: randomized controlled trial
VAS: visual analogue scale

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Computer-Mediated Communication in Adults With and Without Moderate-to-Severe Traumatic Brain Injury: Survey of Social Media Use

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Abstract

Background: Individuals with a history of traumatic brain injury (TBI) report fewer social contacts, less social participation, and more social isolation than noninjured peers. Cognitive-communication disabilities may prevent individuals with TBI from accessing the opportunities for social connection afforded by computer-mediated communication, as individuals with TBI report lower overall usage of social media than noninjured peers and substantial challenges with accessibility and usability. Although adaptations for individuals with motor and sensory impairments exist to support social media use, there have been no parallel advances to support individuals with cognitive disabilities, such as those exhibited by some people with TBI. In this study, we take a preliminary step in the development process by learning more about patterns of social media use in individuals with TBI as well as their input and priorities for developing social media adaptations.

Objective: This study aims to characterize how and why adults with TBI use social media and computer-mediated communication platforms, to evaluate changes in computer-mediated communication after brain injury, and to elicit suggestions from individuals with TBI to improve access to social media after injury.

Methods: We conducted a web-based survey of 53 individuals with a chronic history of moderate-to-severe TBI and a demographically matched group of 51 noninjured comparison peers.

Results: More than 90% of participants in both groups had an account on at least one computer-mediated communication platform, with Facebook and Facebook Messenger being the most popular platforms in both groups. Participants with and without a history of TBI reported that they use Facebook more passively than actively and reported that they most frequently maintain web-based relationships with close friends and family members. However, participants with TBI reported less frequently than noninjured comparison participants that they use synchronous videoconferencing platforms, are connected with acquaintances on the web, or use social media as a gateway for offline social connection (eg, to find events). Of the participants with TBI, 23% (12/53) reported a change in their patterns of social media use caused by brain injury and listed concerns about accessibility, safety, and usability as major barriers.

Conclusions: Although individuals with TBI maintain social media accounts to the same extent as healthy comparisons, some may not use them in a way that promotes social connection. Thus, it is important to design social media adaptations that address the needs and priorities of individuals with TBI, so they can also reap the benefits of social connectedness offered by these

platforms. By considering computer-mediated communication as part of individuals' broader social health, we may be able to increase web-based participation in a way that is meaningful, positive, and beneficial to broader social life.

KEYWORDS

traumatic brain injury; social media; disability; rehabilitation; cognitive communication

Introduction

Computer-Mediated Communication and Social Participation

Social media and other computer-mediated communication (CMC) platforms are ubiquitous parts of everyday life and have radically altered how we work, live, and build and maintain social networks. CMC includes any form of web-based communication, which may be synchronous (eg, video conferencing platforms) or asynchronous (eg, web-based messaging) and may involve the exchange of text, audio, or video messages for professional or social purposes. Within this realm, more than 3 billion people worldwide use social media platforms, such as Facebook, Twitter, and Instagram [1]. Users on social media may participate actively by broadcasting personal or nonpersonal information and providing feedback on others' posts, or they may participate passively by observing information posted by others [2-5]. Depending on how they use social media, individuals may derive different benefits. For example, social media users may derive greater social capital (or value from web-based relationships) if they use social media for active communication, have a diverse web-based network, and increase web-based social connectedness [6].

Tailored Social Media Adaptations to Increase Access for Individuals With Disabilities

For many individuals with disabilities, social media platforms have the potential to overcome existing barriers to social participation [7]. For example, individuals with reduced or limited mobility may be able to engage in social activities where in-person attendance is prohibitive. There have also been increasing calls to foster social media accessibility for those with sensory differences. For instance, it has become more common to add alternative text to images on social media platforms to reduce participation barriers for individuals with certain visual disabilities [8]. These efforts have allowed many individuals with motor and sensory disabilities to increase participation in this ubiquitous part of daily modern social life.

Traumatic Brain Injury and Expanding Social Media Adaptation for Cognitive Disabilities

Adolescents and adults with traumatic brain injury (TBI) often report being socially isolated [9] and could benefit from social media participation. However, many of these individuals have cognitive disabilities that may affect social media use. Individuals with TBI may experience changes in memory, social perception, and social communication [10] and thus may find it more challenging to perceive text-based social cues in social media than cues present in face-to-face communication [11,12]. TBI-related memory and learning disabilities may make it difficult to keep up with evolving requirements of regularly updating social media platforms [3], and reduced attention may create challenges parsing critical information from cluttered news feeds [13].

Tailored adaptations may allow individuals with cognitive disabilities to access and benefit from social media more easily. However, adaptations for individuals with motor and sensory disabilities have not been paralleled by advances that address barriers to social media participation for individuals with *cognitive* disabilities [3,14], such as those experienced by many individuals with TBI. Given that participation in social media platforms is a critical part of day-to-day social communication for many adults, increasing access to CMC and social media platforms may hold significant promise for increasing overall social participation for individuals with TBI [2,3,13].

It is critical to understand how TBI-related cognitive and communication challenges affect access to and use of social media, so we can design apps that support access for all. For example, TBI may affect overall access, such that individuals with TBI are less likely to use social media than noninjured peers. Alternatively, it may be that individuals with TBI use social media at similar rates to noninjured peers but do not reap the same social benefits because of challenges with cognition and communication. Thus, the first step in developing tools that will increase social media success in individuals with TBI is to gather more information about how individuals with TBI use social media and how brain injury affects social media use.

Social Media Use After TBI

There is an emerging body of research directed at understanding social media use in individuals with TBI. Perhaps consistent with the fact that current social media platforms are not designed with individuals with cognitive disabilities in mind, adults in the chronic phase of TBI report using social media less frequently than noninjured peers [3] and indicate that they face significant challenges with accessibility and usability [15,16]. Baker-Sparr et al [3] surveyed a large cohort of individuals with chronic TBI (n=337) on whether and how they use the internet and found that although the proportion of internet users with TBI was high (250/337, 74.1%), it was significantly lower than general population estimates of internet usage (84%) [17]. In this survey, 14.8% (37/250) of individuals with TBI reported that brain injury had somewhat affected their ability to use the internet, listing memory problems, visual challenges, and difficulty with attention as barriers [3].

Consistent with these responses, other work by Ketchum et al [18] has shown a positive association between social internet use and in-person social participation in individuals with TBI, suggesting that individuals with TBI are not likely to use social media as an alternative to social communication. Instead, they

may face many of the same barriers and facilitators on the web as they do in person.

Brunner et al [13] interviewed 13 adults in the chronic phase after an acquired brain injury (traumatic or nontraumatic) about their use of social media. Facebook was the most popular social media platform among interviewees (consistent with Baker-Sparr et al [3]), followed by Twitter and Instagram. Most participants reported that they had help setting up their social media accounts and that they use social media more than once a day. All participants stated that they were motivated to use social media to stay connected with others, and some (2/13, 15% of interviewees) reported using social media to help other people with brain injury. Some participants reported feeling overwhelmed or confused by social media, and those who felt confused by a given platform were likely to give up using it [13].

Our study extends previous work in several ways. First, we examined patterns of social media use in adults with TBI and a demographically matched comparison group. The use of a matched comparison group allows us to understand how patterns may differ between individuals with and without a history of TBI who are similar in demographic variables that may affect CMC use (eg, age and education). Second, we asked specific questions about *how* usage has changed as a result of TBI, rather than just *if* usage has changed, and solicit direct suggestions for improving social media technology support for individuals with TBI. Asking individuals with TBI for specific input on improving social media participation aligns with national and international priorities for TBI rehabilitation research that includes patient-reported outcomes to support health and independence [19]. This study is, to our knowledge, the first in-depth survey of social media use of individuals with TBI and matched peers in the United States and has a larger sample size than previous interview-based studies, allowing us to combine breadth and depth in understanding patterns of social media use after brain injury. Together, these study characteristics increase experimental rigor and expand our knowledge on how individuals with TBI use social media, if and how their use of social media has changed following their brain injury, and the nature of the barriers they face.

Study Objectives

This study had three specific aims: (1) to characterize how and why adults with TBI use social media and CMC platforms, (2) to evaluate changes in CMC after brain injury, and (3) to elicit suggestions from individuals with TBI to improve access to social media after injury.

Methods

Participants

Participants (or respondents) were 53 individuals with moderate-to-severe TBI (28 women) and 51 noninjured comparison (NC) participants (29 women). All participants were recruited from Nashville, Tennessee, United States, and the surrounding areas, and the groups were demographically matched for age and education. The mean age was 37.7 years (SD 9.6) for the TBI group and 36.4 years (SD 10.4) for the NC

group, with no significant between-group difference (t_{102}=0.685; P=.50). The mean years of education were 15.0 (SD 2.6) for respondents with TBI and 15.1 (SD 2.1) for the NC group, with no significant between-group difference (t_{102}=0.581; P=.56).

Individuals with TBI were recruited through the Vanderbilt Brain Injury Patient Registry and had no self-reported preinjury history of neurological or cognitive disability. All individuals with TBI were in the chronic phase of injury (>6 months postonset, mean time since onset 74.1 months, SD 66.0) and sustained their injuries as adults. Injury-related information was obtained from medical records and semistructured participant interviews. Injury etiologies included motor vehicle accidents (n=27), falls (n=10), being struck by a vehicle as a pedestrian (n=4), motorcycle or snowmobile accidents (n=3), nonmotorized vehicle accidents (eg, biking, n=3), assault (n=3), and being struck by a moving object (n=3). TBI severity was determined using the Mayo Classification System [20], so injuries were moderate-to-severe if at least one of the following criteria were met: (1) Glasgow Coma Scale score <13 within 24 hours of acute care admission, (2) positive neuroimaging findings (acute computed tomography findings or lesions visible on chronic magnetic resonance imaging), (3) loss of consciousness >30 minutes, or (4) posttraumatic amnesia >24 hours.

NC participants were recruited from the NC participant pool in the Vanderbilt Brain Injury Patient Registry and had no self-reported history of neurological or cognitive disability.

Survey

The data reported here are part of a larger survey examining different aspects of social media use for individuals with TBI. For all participants, the survey included questions about social media platform use, activities on social media, types and quality of relationships with social media friends, and perceived benefits and drawbacks of using social media. Participants with TBI also answered questions about how social media use has changed since injury, provided suggestions for researchers and clinicians interested in decreasing barriers and supporting social media use, and responded to mockups of potential Facebook modifications.

In designing the survey, we designated some questions to focus specifically on Facebook usage because we anticipated high usage of Facebook across both groups based on national data [1] and previous work on social media in TBI [3,13]. We sought to acquire additional information about how and why individuals with TBI use Facebook to guide the future design of technology-based aids around the Facebook platform, given its high usage among individuals with TBI.

Here, we focus on questions related to our goals in characterizing social media use in TBI, assessing postinjury differences in CMC, and describing barriers to social media use for individuals with TBI. We included items from the Social Networking Usage Questionnaire [21] to assess participants' activities on social media. We also included questions from an analysis of Facebook friend networks [22] to evaluate participants' web-based social networks and from an assessment of web-based social capital formation [6] to assess how individuals with and without TBI use social media in passive

and active ways. Items from these scales are presented in the *Results* section. Some of these items were modified for participants with TBI. For example, we added TBI-related examples to tailor questions about social media advocacy and groups. In addition, we collapsed response options on the web-based social capital formation scale [6] from five items (almost never, rarely, sometimes, almost every day, and multiple times a day) to three items (never or almost never, sometimes, and often) to reduce the cognitive load on respondents, given the survey's overall length. As we did not intend to directly compare these responses with results from previous studies, modifying established scales maintained a connection to how social media use is studied by field experts while remaining feasible for participants with TBI.

Procedures

The procedures for this study were approved by the Human Research Protections Program at Vanderbilt University. Participants received a link to complete the survey on the web via REDCap (Research Electronic Data Capture) [23]. All participants completed the survey between June and September 2020. The survey consisted of up to 280 questions (a mix of multiple-choice and free response), but in this study, we focus on 15 questions relevant to social media usage and changes in usage related to TBI (Multimedia Appendix 1). In some cases, questions only appeared if respondents had previously selected a given response. For example, individuals only described their participation frequency for the social media platforms they reported using. The survey took approximately 30 to 45 minutes for the NC participants to complete. As participants with TBI responded to more questions, they received links to take the survey in two parts, lasting approximately 30 minutes each.

Analysis and Interpretation

The goal of this study was to explore how and why individuals with and without a history of TBI use social media and CMC platforms as well as existing barriers to social media use for individuals with TBI. Consistent with this exploratory goal, we used descriptive statistics, expecting that the data would serve as the foundation for future hypothesis-driven research on technology-based social media interventions for individuals with TBI [24].

The survey provided several opportunities to add information via free-text responses to open-ended questions, and we have reported these responses descriptively. Although it is important to not overinterpret those responses (as we did not understand the forces that caused only some individuals to respond to these

questions), we included them because they could generate and refine questions for future research [24].

Results

Survey Overview

Responding to individual questions was voluntary, and some questions only appeared via branching logic, depending on previous responses. Therefore, not all participants answered all questions. The number of individuals who responded to a given question is listed in parentheses. Response percentages for each group are listed for multiple-choice questions; proportions are not listed for free-text responses. On some questions, respondents could choose more than one option, so the total percentages reported for those questions may exceed 100%.

CMC Platforms and Frequency of Use

Overall, 96% (51/53) of participants with TBI and 98% (50/51) of NC participants reported that they currently hold an account on at least one CMC platform. Participants frequently used more than one platform, with participants with TBI holding an account on an average of 5.66 (SD 3.26) platforms and NC participants holding an account on an average of 7.49 (SD 3.57) platforms.

Table 1 provides the proportion of participants in each group, reporting that they use certain platforms. Facebook was the most popular platform for both groups (TBI: 41/51, 80%; NC: 43/50, 86%). Facebook Messenger came next for participants with TBI, followed by Instagram, FaceTime, and Snapchat. Twitter was popular with NC participants (23/50, 46%), although it was not used by as many participants with TBI (13/51, 26%). Participants with TBI reported lower rates of usage for LinkedIn (TBI: 19/51, 37%; NC: 29/50, 58%) and Pinterest (TBI: 16/51, 31%; NC: 23/50, 46%) as well as other videoconferencing platforms, such as Zoom (TBI: 19/51, 37%; NC: 31/50, 62%) and Skype (TBI: 13/51, 26%; NC: 24/50, 48%).

Participants could also include, in free-text form, the names of platforms they use that were not on the survey list. A total of five platforms were reported: GroupMe, Amazon Show, WebEx for participants with TBI, and Kik and Slack for NC participants.

We asked the participants to indicate how often they used platforms where they had an account. Table 2 provides the frequency of use of platforms used by at least 25% of participants with TBI. The full table, including all platforms, is available in Multimedia Appendix 1.

Table 1. Proportion of participants who endorsed having an account on a given social media platform.

Platform	Traumatic brain injury (n=51), n (%)	Noninjured comparison (n=50), n (%)
Bumble	7 (14)	1 (2)
Discord	4 (8)	5 (10)
Facebook	41 (80)	43 (86)
Facebook Messenger	38 (75)	40 (80)
FaceTime	25 (49)	28 (56)
Google Hangouts	7 (14)	13 (26)
Hinge	4 (8)	4 (8)
Instagram	30 (59)	37 (74)
LINE	0 (0)	0 (0)
LinkedIn	19 (37)	29 (58)
Pinterest	16 (31)	23 (46)
Quora	0 (0)	3 (6)
Reddit	8 (16)	11 (22)
Skype	13 (26)	24 (48)
Snapchat	25 (49)	23 (46)
Telegram	1 (2)	1 (2)
TikTok	3 (6)	9 (18)
Tinder	6 (12)	4 (8)
Tumblr	3 (6)	7 (14)
Twitter	13 (26)	23 (46)
Viber	0 (0)	2 (4)
WhatsApp	15 (29)	18 (36)
Zoom	19 (37)	31 (62)
Other platform	3 (6)	3 (6)

Table 2. Frequency of use for respondents on a given platform.

Platform[a]	Yearly (%)		Monthly (%)		Weekly (%)		Multiple times per week (%)		Daily (%)		Multiple times per day (%)	
	TBI[b]	NC[c]	TBI	NC	TBI	NC	TBI	NC	TBI	NC	TBI	NC
Facebook (TBI: n=41; NC: n=43)	0	5	2	9	12	2	10	16	30	21	46	47
Facebook Messenger (TBI: n=38; NC: n=40)	5	10	8	18	16	20	26	28	24	12	21	12
FaceTime (TBI: n=25; NC: n=28)	0	11	48	29	12	36	28	21	8	0	4	3
Instagram (TBI: n=30; NC: n=37)	7	3	17	5	10	3	7	11	13	32	46	46
LinkedIn (TBI: n=19; NC: n=29)	26	17	16	44	32	24	10	7	16	4	0	4
Pinterest (TBI: n=16; NC: n=23)	31	26	25	35	13	13	19	17	6	0	6	9
Skype (TBI: n=13; NC: n=23)	46	30	31	35	0	9	8	4	15	13	0	9
Snapchat (TBI: n=25; NC: n=23)	8	17	16	0	16	22	20	17	12	17	28	27
Twitter (TBI: n=13; NC: n=22)	23	14	15	27	15	14	23	9	9	14	15	22
WhatsApp (TBI: n=15; NC: n=18)	33	39	33	27	20	11	0	6	14	6	0	11
Zoom (TBI: n=19; NC: n=31)	11	3	31	10	21	29	11	29	15	19	11	10

[a]This table includes platforms where at least 25% of participants with traumatic brain injury endorsed having an account.

[b]TBI: traumatic brain injury.

[c]NC: noninjured comparison.

Reasons for Not Using Social Media

We asked participants if there were any social media platforms where they would like to have an account but do not currently. A total of 4% (2/52) of participants with TBI reported wanting to use LinkedIn, TikTok, and Tinder. A total of 8% (4/51) of NC participants reported that they would like to have accounts on Facebook, Reddit, Snapchat, TikTok, Tumblr, and Twitter. In a separate question, we asked participants to explain why they did not use these platforms. The participant with TBI who responded to this question stated, "I don't like the way I communicate on them. I don't like the way I obsess over how often I am on them." A total of 2 NC participants also noted that time is a factor in not setting up additional social media accounts.

We asked participants who do not have a Facebook account to explain via free text why they do not use the platform. Participants with TBI stated that they were concerned about the nature of information available on Facebook (eg, falsehoods, n=3) or that they found Facebook to be "toxic" or "superficial" (n=2). One participant with TBI stated a preference for in-person

communication, "I like eye contact, and raw emotion, not emojis." The most frequent reason NC participants gave for not using Facebook was that they found it unnecessary or a waste of time (n=3).

Activities on Social Media

We asked participants about how they use social media with options adapted from the Social Networking Usage Questionnaire [21]. Table 3 provides social media activities endorsed by participants with TBI and NC participants. Participants with TBI reported numerically less frequently than NC participants that they use social media to keep up with friends and family (TBI: 44/52, 85%; NC: 49/50, 98%) or to obtain information regarding social events (ie, to use CMC for relationships and events happening beyond social media; TBI: 24/52, 46%; NC: 33/50, 66%). Participants with TBI also reported numerically less frequently than NC participants that they use social media to obtain information (eg, to discover new things, TBI: 26/52, 50%; NC: 36/50, 72%; to follow current events, TBI: 25/52, 48%; NC: 28/50, 56%) or to post about their daily lives (TBI: 19/52, 37%; NC: 25/50, 50%).

Table 3. Percentage of participants endorsing different uses of social media (adapted from a study by Gupta and Bashir [21]).

Type of use	TBI[a] (n=52), n (%)	Noninjured comparison (n=50), n (%)
Advocating for specific causes (eg, promoting TBI-related organizations or events)	8 (15)	14 (28)
Creating my social identity	11 (21)	17 (34)
Discovering new things	26 (50)	36 (72)
Following thought leaders or celebrities	7 (14)	21 (42)
Getting information regarding social events	24 (46)	33 (66)
Getting job-related information	19 (37)	20 (40)
Keeping in touch with friends and family	44 (85)	49 (98)
Looking for support groups	4 (8)	4 (8)
Providing support to others	10 (19)	15 (30)
Searching for specific information (eg, information about TBI)	11 (21)	17 (34)
Staying up to date with news and current events	25 (48)	28 (56)
Sharing the happenings of daily life	19 (37)	25 (50)
Sharing new ideas	10 (19)	7 (14)

[a]TBI: traumatic brain injury.

For those individuals who reported having a Facebook account (42 participants with TBI and 43 NC participants), we asked questions about their specific use of the platform. First, we asked them what kinds of friends they have on Facebook (options adapted from a study by Manago et al [22]; Table 4).

Both groups most frequently reported being Facebook friends with close friends and family members. Participants with TBI reported numerically less frequently than NC participants that they were Facebook friends with acquaintances, coworkers, people they had met once, or people they casually dated.

Table 4. Types of Facebook friends endorsed by participants (adapted from a study by Manago et al [22]).

Type of Facebook friend	Traumatic brain injury (n=42), n (%)	Noninjured comparison (n=43), n (%)
Acquaintance	33 (79)	41 (95)
Band, musical artist, or other celebrity	14 (33)	18 (42)
Best friend	36 (86)	35 (81)
Classmate	33 (79)	33 (77)
Coworker	32 (76)	37 (86)
Current significant other (eg, girlfriend or boyfriend)	28 (67)	21 (49)
Family member	38 (91)	39 (91)
Fellow club member	7 (17)	16 (37)
Fraternityor sorority brother or sister	6 (14)	5 (12)
Friend of a friend	27 (64)	29 (67)
Good friend	38 (91)	38 (88)
High school friend	35 (83)	39 (91)
Neighbor	20 (48)	16 (37)
Web-based friend only (never met in person)	11 (26)	14 (33)
Past romantic partner	20 (48)	24 (56)
Roommate	16 (38)	17 (40)
Someone you do not know	10 (24)	12 (28)
Someone you casually dated	14 (33)	22 (51)
Someone you met in a different country	12 (29)	18 (42)
Someone you only met once	19 (45)	30 (70)
Teammate	14 (33)	15 (35)
Very good friend	36 (86)	36 (84)

We asked participants questions from a scale on social capital building [6] to assess how they use Facebook actively (eg, creating their own posts), passively (eg, looking through the newsfeed), for social searching (eg, actively searching for and adding friends) and browsing (eg, looking at others' profiles but not adding them as friends), and for private communication (Table 5). Participants with and without a history of TBI reported more frequently that they use Facebook passively than actively. Although not by large numerical differences, participants with TBI reported more frequently, in general, than NC participants that they use Facebook for social browsing (eg, browsing through others' profiles) and social searching (eg, looking for new friends to add).

Table 5. Facebook users' social capital building activities (adapted from a study by Koroleva et al [6]).

Activity	Never or almost never, n (%)		Sometimes, n (%)		Often, n (%)	
	TBI[a] (n=42)	NC[b] (n=43)	TBI (n=42)	NC (n=43)	TBI (n=42)	NC (n=43)
Active participation						
Post something	14 (33)	18 (42)	23 (55)	18 (42)	5 (12)	7 (16)
Share thoughts and feelings	26 (62)	28 (65)	14 (33)	13 (30)	2 (5)	2 (5)
Share something you are interested in	14 (33)	18 (42)	21 (50)	20 (47)	7 (17)	5 (12)
Share your impressions with your friends	24 (57)	24 (56)	13 (31)	14 (33)	5 (12)	5 (12)
Donate to a cause on Facebook	30 (71)	31 (72)	10 (24)	12 (28)	2 (5)	0 (0)
Passive following						
Follow your friends' news	10 (24)	7 (16)	18 (43)	13 (30)	14 (33)	23 (54)
Look through your newsfeed	5 (12)[c]	2 (5)	15 (37)[c]	13 (30)	21 (51)[c]	28 (65)
Click on content shared by friends	9 (21)	3 (7)	17 (41)	25 (58)	16 (38)	15 (35)
Social browsing						
Browse your friends' profiles	13 (31)	7 (16)	19 (45)	29 (67)	10 (24)	7 (16)
Browse through friends of your friends	23 (55)	22 (51)	12 (29)	16 (37)	7 (17)	5 (12)
Look at profiles of people not on your Facebook friends list	21 (50)	27 (63)	15 (36)	12 (28)	6 (14)	4 (9)
Social searching						
Search for people to add	26 (62)	31 (72)	12 (29)	11 (26)	4 (10)	1 (2)
Send friendship requests	17 (42)[c]	19 (44)	20 (49)[c]	22 (51)	4 (10)[c]	2 (5)
Add people suggested by Facebook	24 (57)	26 (61)	14 (33)	16 (37)	4 (10)	1 (2)
Private communication						
Send private messages	10 (24)	13 (30)	23 (55)	22 (51)	9 (21)	8 (19)
Chat	16 (38)	19 (44)	20 (48)	20 (47)	6 (14)	3 (9)

[a]TBI: traumatic brain injury.

[b]NC: noninjured comparison.

[c]n=41.

Reflections on CMC Use After TBI

We asked participants with TBI whether their use of social media has changed because of the injury, and 23% (12/53) responded affirmatively. Next, we asked 12 participants to describe the changes via free text. A total of 5 participants reported that they spend more time on social media than before their injuries, whereas 2 participants reported spending less. A total of 2 participants stated that they now use social media to keep up with TBI-related groups. Another 2 participants endorsed being more careful in their use of social media (ie, whom they follow). Some participants stated that using social media has become harder postinjury (because of sensitivity to light or screens: n=1; increased stress: n=1; or feelings of insecurity: n=1), but one participant noted that social media is helpful in managing a memory deficit.

We also asked participants with TBI to provide suggestions for researchers and clinicians interested in improving the experience of using social media for individuals with TBI, and 32% (17/53) of participants provided free-text suggestions. Some participants worried that social media may be detrimental for people with

TBI (n=3) or noted that clinicians should discourage overuse (n=2). In contrast, other participants (n=2) noted that social media may be helpful for individuals with TBI, particularly for learning and social interactions that feel less stressful than face-to-face communication. Other participants suggested reducing "extra content" (eg, advertisements and recommended posts, n=2), which can feel overwhelming, or increasing provider presence on social media (eg, via support groups, n=2).

Discussion

Principal Findings

Overview

The primary goal of this survey was to understand the patterns of social media use among individuals with TBI. We compared their social media usage with peers without a history of TBI, solicited feedback on how brain injury changes social media use, and requested suggestions as to how best to support individuals with TBI in their social media use. Several key observations have emerged.

Variability in Social Media Use for Adults With and Without TBI

Social communication differences are a hallmark of the observed cognitive disability in TBI [25]. Adults with TBI report fewer social contacts, less social participation, and more social isolation than noninjured peers [9]. This reduced social participation has negative effects on employment, health, and quality of life [26]. As the previous literature suggests that these challenges may extend to web-based communication via social media [2,3,13,18], it is important to understand how and where individuals with TBI may face challenges in social media use. As the first step in this line of work, we examined social media usage to understand how TBI may affect participation in social media, as well as patterns of use for those who engage in this form of web-based communication.

In this study, a majority (51/53, 96%) of participants with a history of TBI were reported using at least one social media platform. All participants in this study had access to the internet to complete the survey, and the proportion of social media users was higher in the TBI group than in previous work on TBI (eg, Baker-Sparr et al [3], who reported that 79%, 197/250, of internet users with TBI in their sample had at least one social media account). These findings suggest that social media use is ubiquitous among individuals with TBI, just as it is for individuals without a history of TBI.

In several ways, participants with TBI were congruent with NC participants in their use of social media. The groups had the same most popular social media platforms (Facebook and Facebook Messenger). These popular platforms were also consistent with previous studies of individuals with TBI (eg, Baker-Sparr et al [3] and Brunner et al [13]). Participants with and without a history of TBI were also similar in that they more frequently use social media passively (eg, to read the news feed) than actively (eg, to post new things). This observation was consistent with previous work [13], suggesting that individuals with TBI, like their noninjured peers, may be more likely to use social media to observe others than to actively participate in themselves. Both groups were also reported most frequently that they are Facebook friends with close friends and family members, suggesting that participants with TBI and NC participants both use social media more to foster existing interpersonal relationships than to actively seek new ones. Future work might consider how these patterns of social media use reflect neural activity in individuals with and without a history of TBI [4].

We also found that NC participants reported more frequently than participants with TBI that they use some platforms, including LinkedIn, Zoom, and Skype. Even participants with TBI who have accounts on these platforms report using them less frequently than NC participants. It is interesting to note that many of the platforms used more frequently by NC participants (eg, LinkedIn, Zoom, and Skype) are often used in a professional context. In fact, participants with TBI were more similar to NC participants in their use of FaceTime, another videoconferencing app that is not often used in a professional context. Individuals with TBI may be less likely to hold careers that depend on web-based communication or where web-based networking is critical to success. Although speculative, it is worth considering whether the relationship is bidirectional, with the challenges of CMC limiting the interest of or opportunities for adults with TBI in work that involves a great deal of web-based communication. In fact, our results were consistent with previous work [13], suggesting that few people with TBI use social media for professional networking or TBI-related advocacy. In today's connected digital world, addressing this *digital divide* may allow individuals with TBI to increase their professional and personal self-advocacy on a broader scale [27].

Although both individuals with TBI and noninjured peers use social media more passively than actively, some individuals with TBI may be less likely than their noninjured peers to use CMC in a way that translates to in-person communication, relationships, and events happening beyond social media [6]. NC participants reported more frequently than participants with TBI that they use social media to keep up with friends and family or to get information regarding social events. NC participants also reported more frequently that they use social media for more distant networking opportunities. NC participants reported more frequently than participants with TBI that they are Facebook friends with acquaintances, coworkers, or people they had met once or casually dated. Consistent with previous work [18], individuals with TBI may not use social media as an alternative to in-person communication but rather face similar challenges in web-based and offline communication that may prevent them from capitalizing on the benefits of social media. Intervening in CMC, just as in-person communication, may allow individuals with TBI to increase their active participation in web-based activities that may translate to relationships and reduce social isolation beyond social media.

Social Media Presents Challenges and Opportunities for Adults With TBI

Many of the self-reported group differences in patterns of social media use in this study may be driven by a subset (12/53, 23%) of participants with TBI who reported changes in their social media use caused by TBI. This subgroup of individuals who readily identify injury-related social media changes is consistent with considerable heterogeneity in cognitive and disability profiles for individuals with a history of brain injury [10]. For example, it is estimated that approximately one-third of individuals with TBI exhibit social cognition deficits [28]. It is important to note that cognitive impairment (eg, in memory or social communication) may not always result in a functional disability that affects social media use, especially for individuals who develop or use adaptive strategies.

As with any intervention targeting the heterogeneous group of individuals with a history of TBI, it is likely that a critical part of a successful social media intervention will be identifying those individuals who will benefit. Future work should consider whether, and if so how, the subgroups of individuals with postinjury changes to social media use and social cognition overlap (ie, if the subgroup of participants who report social media changes are experiencing an extension of challenges present in offline social communication [18]). However, it is important to consider how cognitive-communication adaptations might support CMC use for some individuals with TBI who do

not report a change in their use of social media, possibly because of a lack of insight or deficit awareness. Future intervention work should assess the efficacy of social media modifications in increasing CMC success for individuals with TBI who do and do not report changes to their social media use postinjury.

Research on social communication in adults with TBI has revealed impairments in perception of social cues even in face-to-face, synchronous communication [29-34]. In this study, participants with TBI reported less frequently than NC participants that they use some platforms involving synchronous communication (eg, Zoom and Skype), although they were more comparable in their use of FaceTime. This pattern was consistent with findings from a separate survey on the COVID-19 pandemic [35], in which individuals with a history of TBI reported that they found video chat to be less successful than face-to-face communication, and some participants stated that impoverished visual and verbal cues via video chat make it more difficult to read social signals. In this context, it is interesting to consider how asynchronous communication via social media may prove even more challenging for some individuals with TBI than synchronous video chat. Communicating successfully via text on social media (eg, via Facebook posts) requires the integration of a broad range of social and contextual multimedia cues, as well as considerable social inferencing, without any verbal information or the ability to read gestures or facial expressions. As such, it may be useful to support individuals with TBI in isolating important social cues (eg, keywords and emojis) available in communication over social media.

There are certainly risks to social media use, which were identified by some participants in our study. Some individuals with TBI may be more vulnerable to social media overuse, cyberbullying, or web-based manipulation because of disabilities in self-regulation, decision-making, and resiliency [2,13]. In an earlier study [13], individuals with TBI reported being bullied on the internet at a high rate. As such, rather than issuing a blanket recommendation that individuals with TBI use social media to increase their participation, it is critical to consider how to support individuals with TBI in using social media in a way that is beneficial, as well as filtering and responding to critical information when on the web [3,13].

At the same time, there is great opportunity to reduce barriers to social media use for individuals with TBI. Some preliminary work [18] has suggested that using social media helps individuals with TBI to increase their broader social participation. The increased movement for disability advocacy on the web presents an opportunity for adults with TBI to engage with others who have shared experiences [2,7,13], and several participants in this study identified increased opportunities for TBI engagement as an area for social media growth. Furthermore, supporting individuals with TBI in their use of social media may reduce the *digital divide* with regard to web-based professional networking and using social media in a way that translates to real-world professional and personal opportunities [27].

Designing Tailored and Effective Social Media Supports

This study represents a critical step in developing technology-based social media interventions for individuals with TBI, as stakeholders should have a guiding voice in rehabilitation research [19]. Here, individuals with TBI exhibited social media usage patterns that are broadly similar to noninjured peers, with limited exceptions. However, a proportion of respondents identified barriers that affect their social media use. In the context of designing social media interventions, these findings raise the question of whether individuals with TBI receive the same benefits from social media use as noninjured peers. For example, it is possible that some individuals with TBI do not explore or interact with social media in the same way as their peers. It may be challenging to sample or recall information from visually complex, dynamic displays or to read and broadcast appropriate web-based social cues in a way that increases broader social capital. Future work should assess this open question to determine the critical places for technology-based interventions for social media use in TBI.

Evaluating the effectiveness of an intervention should consider not only communication success but also the accessibility, usefulness, and acceptance of that intervention for individuals with TBI [36]. As technology support is more likely to create meaningful positive changes when in regular use, it is critical to solicit and follow the guidance of individuals with TBI when considering where and how interventions can support successful social media use.

Limitations to Generalizability

The results of this study provide a snapshot of how individuals with TBI use social media and their priorities for potential social media–based interventions. As we administered our survey on the web, all participants in this study had regular access to email, and thus, our sample may not be fully representative of the spectrum of internet use in TBI. Here, we present descriptive data that may form the foundation for future hypothesis-driven intervention research in this area [24]. Our participants provided initial responses as to how we might improve social media support for individuals with TBI, but further studies may build on these results to request feedback on specific intervention options. Additional studies with larger sample sizes will also allow for informed hypotheses and direct statistical tests of between-group differences in social media use.

Conclusions

Consistent with previous work [2,3,13], cognitive disabilities may add to the social media maze for some individuals with TBI, and designing supports that mitigate these challenges may increase web-based and real-world social participation. Although it is possible that only a subset of individuals with TBI would benefit from technology-based social media support, to the extent that social participation on the web helps to reduce the physical and psychological burdens of loneliness, developing such interventions is warranted. As technology evolves, the principles of these interventions should be well-defined, evidence-based, and generalizable beyond a single platform. They should also reflect the priorities and input of individuals

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with TBI [19,36]. Furthermore, given the heterogeneity of social media patterns in this sample, interventions should be easily tailored to a given individual. By considering CMC as part of an individual's broader social health, we stand to alter web-based participation in a way that is meaningful, positive, and beneficial to broader social life.

Acknowledgments

Conflicts of Interest

None declared.

Multimedia Appendix 1
Survey questions and full frequency table.
[DOCX File , 26 KB - rehab_v8i3e26586_app1.docx]

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Abbreviations

CMC: computer-mediated communication
NC: noninjured comparison
REDCap: Research Electronic Data Capture
TBI: traumatic brain injury

Original Paper

Tele-Rehabilitation to Combat Rehabilitation Service Disruption During COVID-19 in Hong Kong: Observational Study

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Abstract

Background: A tele-rehabilitation platform was developed to improve access to ambulatory rehabilitation services in Hong Kong. The development was completed in October 2019 and rolled out for use to occupational therapists, physiotherapists, and speech therapists. During the COVID-19 pandemic, rehabilitation services were severely interrupted. Tele-rehabilitation was used extensively to meet the demand for rehabilitation service delivery.

Objective: The aims of this study were to (1) describe the design and development process of a tele-rehabilitation service, and (2) study how the tele-rehabilitation platform was used to overcome the disruption of rehabilitation service during the COVID-19 pandemic.

Methods: Tele-rehabilitation was developed utilizing 4 core determinants of Unified Theory of Acceptance and Use of Technology as guiding principles. A generic prescription platform, called the activity-based prescription system, and a mobile app, called the Rehabilitation App, were built. Five outcomes were used to examine the utilization of tele-rehabilitation both before and during the pandemic: throughput, patient demographic, patient conditions, workforce, and satisfaction from patients and staff.

Results: There was a tremendous increase in the use of tele-rehabilitation during pandemic. The total number of patients (up until July 2020) was 9101, and the main age range was between 51 to 70 years old. Tele-rehabilitation was used for a much wider scope of patient conditions than originally planned. More than 1112 therapists, which constituted 50.6% of the total workforce (1112/2196), prescribed tele-rehabilitation to their patients. Moreover, there was a high satisfaction rate from patients, with a mean rating of 4.2 out of 5, and a high adherence rate to prescribed rehabilitation activities (107840/131995, 81.7%).

Conclusions: The findings of our study suggested that tele-rehabilitation in the form of a generic prescription platform and mobile app can be an effective means to provide rehabilitation to patient. During the COVID-19 pandemic, tele-rehabilitation has been used extensively and effectively to mitigate service disruption. Our findings also provide support that there is a high level of satisfaction with tele-rehabilitation; however, a longer duration study is required to demonstrate the sustained use of tele-rehabilitation, especially after the pandemic.

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Introduction

Rehabilitation Demand and Service Gap in Hong Kong

The Hospital Authority is the statutory body responsible for managing public health services in Hong Kong. The Hospital Authority provides over 90% of inpatient care and 30% of outpatient care and is the major provider of rehabilitation service to Hong Kong citizens [1]. The Hong Kong Census and Statistics Department projects that the percentage of older adults—individuals over 65 years of age—will increase from 14.7% in 2014 to 23.3% in 2026 [1]. There is heavy demand for rehabilitation services by the aging population. In 2013, there were approximately 18,000 and 6100 acute admissions for stroke and hip fracture, respectively, treated by Hospital Authority [2], and 38% of stroke patients and 70% of hip fracture patients were transferred to extended care hospitals for rehabilitation. The average length of extended care stay for patients after stroke was 34.4 days, while that for patients with hip fracture was 23.9 days [3]. Ambulatory rehabilitation services are provided to patients upon discharge from hospitals. The Hospital Authority commissioned a territory-wide strategic service framework study on rehabilitation service in 2016 and the report indicated that there were serious problems: (1) inadequate ambulatory rehabilitation service placement, (2) long wait times for service, and (3) inadequate therapy intensity and frequency for patients in need [4]. The above-mentioned inadequacies for ambulatory service (1) hindered the flow of patients from acute hospital to extended care hospital, (2) delayed discharge of patients from extended hospital, and (3) became a barrier to patients' reintegration into the community. In 2018 and 2019, there were over 2.8 million allied health outpatient attendances and over 6 million inpatient and day patient attendances [2]. Stroke, cardiovascular diseases, musculoskeletal diseases or trauma, and respiratory diseases were the 4 major groups requiring intensive rehabilitation services.

To overcome service bottlenecks, especially those for patients after stroke, patients after hip fracture, and older adult patients with frailty, the report [4] recommended the development of tele-rehabilitation and pursued novel service delivery models such as tele-therapy, tele-monitoring, and tele-education. The objective was to improve overall access to rehabilitation services. In line with the recommendations, the Hospital Authority Annual Plan 2019-2020 included the strategic development of mobile solutions to facilitate the public's access to Hospital Authority service [3,4].

Hospital Authority Tele-rehabilitation

Tele-rehabilitation refers to the provision of rehabilitation service at a distance using telecommunication technology as the service delivery medium. It is an alternative means of providing all aspects of care including interviews, physical assessments, diagnoses, interventions, maintenance activities, consultations, education, and training to patients in a remote location [5]. Tele-rehabilitation has been practiced overseas for many years, and there is a lot of research indicating its effectiveness for various kinds of conditions [6-11]. There are a number of benefits, both to patient and family, including (1) potential transportation, cost, and time savings; (2) continuity of patient care; (3) the ability for patients to perform interventions at convenient times, intensity, and sequencing; and (4) the positive effect for the patient of performing rehabilitation in their own social and vocational environment [6]. Tele-rehabilitation has been practiced by different allied health professions since its introduction [7-10], but Hong Kong has lagged in the development of tele-rehabilitation—there are relatively few studies because health care providers have not considered the need for tele-rehabilitation in Hong Kong. However, 1 tele-rehabilitation study [11] in Hong Kong demonstrated the feasibility, efficacy, and high level of acceptance of tele-rehabilitation among community-dwelling patients after stroke.

COVID-19 Outbreak

The tele-rehabilitation platform's development was completed in October 2019. The aim of its development was to provide therapists with a new form of service delivery. Since mid-January 2020, COVID-19 has affected Hong Kong and in late January 2020 rehabilitation services delivery became seriously disrupted, with a 50% drop in attendance. To combat the disruption of service, occupational therapists, physiotherapists, and speech therapists extensively utilized the tele-rehabilitation platform from mid-February 2020 onward, and its content expanded rapidly from early March 2020 onward, gathering momentum during the COVID-19 outbreak.

The aims of this study were to describe the design and development process of the tele-rehabilitation platform and investigate how the tele-rehabilitation platform was used to overcome the disruption of rehabilitation services during the COVID-19 pandemic.

Methods

Theoretical Basis

A technology or innovation can only be considered useful if it is accepted and used in daily clinical practice. There are several criteria to consider in predicting whether target users will actually use the technology. The Unified Theory of Acceptance and Use of Technology [12], based on conceptual and empirical similarities of various technology acceptance models, was used as a framework to guide on the development of the Hospital Authority's tele-rehabilitation platform. The model contained 4 core determinants—(1) performance expectancy (ease of use), (2) effort expectancy (perceived usefulness), (3) organizational facilitating conditions, and (4) social influence—of user's intention to use and actual use behavior of the new technology [12]. *Performance expectancy* is defined as the degree to which an individual believes that the use of the new system will help them improve their job performance. *Effort expectancy* is defined as the degree to which a person perceives the system as easy to use. *Social influence* is defined as the degree to which an individual perceives that important others believe they should use an information system. *Organizational facilitating condition* is defined as the degree to which an individual believes an organizational and technical infrastructure exists to support the use of the system. These determinants applicable to technology acceptance by health care workers [13]. These 4 guiding

principles indicated that the tele-rehabilitation platform should (1) be easy to use; (2) be able to help therapists provide treatment to patients in need; (3) have adequate support and training provided; and (4) be such that the user is well engaged and perceives the importance of its use. By adhering to these principles, we hoped to foster the intention of use and actual use of tele-rehabilitation. The development was user centric and conducted in close collaboration with clinical users and patients.

Requirements and Design

Focus groups were formed to work in close collaboration with physiotherapists, occupational therapists, and speech therapists. An agile approach was used; therapists could test the prototypes during regular focus group meetings and provide feedback. Moreover, patients were invited to try the mobile app and provide comments on a regular basis for continuous user interface improvements.

Tele-rehabilitation has been used for patients after stroke [14-16], in cardiac rehabilitation [17-20], after total knee replacement and total hip replacement [21-24], with multiple sclerosis [25,26], with aphasia and speech disorders [27-29], with cognitive impairments [30,31], and after hip fracture [32,33]. Tele-rehabilitation modes can be grouped into videoconferencing, virtual reality, sensors (or wearables), and mobile apps [9,10]. Different types of tele-rehabilitation have their own advantages and weaknesses. Randomized controlled trials [21,22,26] have demonstrated clinical evidence supporting the effectiveness of tele-rehabilitation. It was stressed by our users that the tele-rehabilitation platform should (1) bridge the service gap in the ambulatory rehabilitation service, (2) enable the therapists to prescribe suitable exercise to patients, and (3) save time for the therapist in view of their current heavy workload. It was emphasized that patients should be able to carry out prescribed rehabilitation activities anywhere and anytime by themselves. Tele-rehabilitation using off-the-shelf technology was favorable [19,34] because it can be easily accessible to patients (ie, without the need to procure and install sophisticated equipment.)

After thorough discussions, it was decided that a new prescription platform and a mobile app would be developed. The utilization of a mobile app in tele-rehabilitation has been supported in many studies [30,31]. After therapist assessment of a patient, exercise videos and reminders could be prescribed through a prescription platform, and the patient could access the prescription through the mobile app. We determined that the prescription platform should be easily accessible and align well with existing clinical workflow of therapist, and the mobile app should be user friendly to older adult users and able to capture the patient's performance and can channel the results of training back to prescribing therapist for treatment evaluation and planning. The team finally concluded upon a design based on these collective requirements (Figure 1)

Figure 1. System design. ABPS: Activity Based Prescribing System; Clinical Management System; DB: database; OT: occupational therapist; PT: physiotherapist; ST: speech therapist.
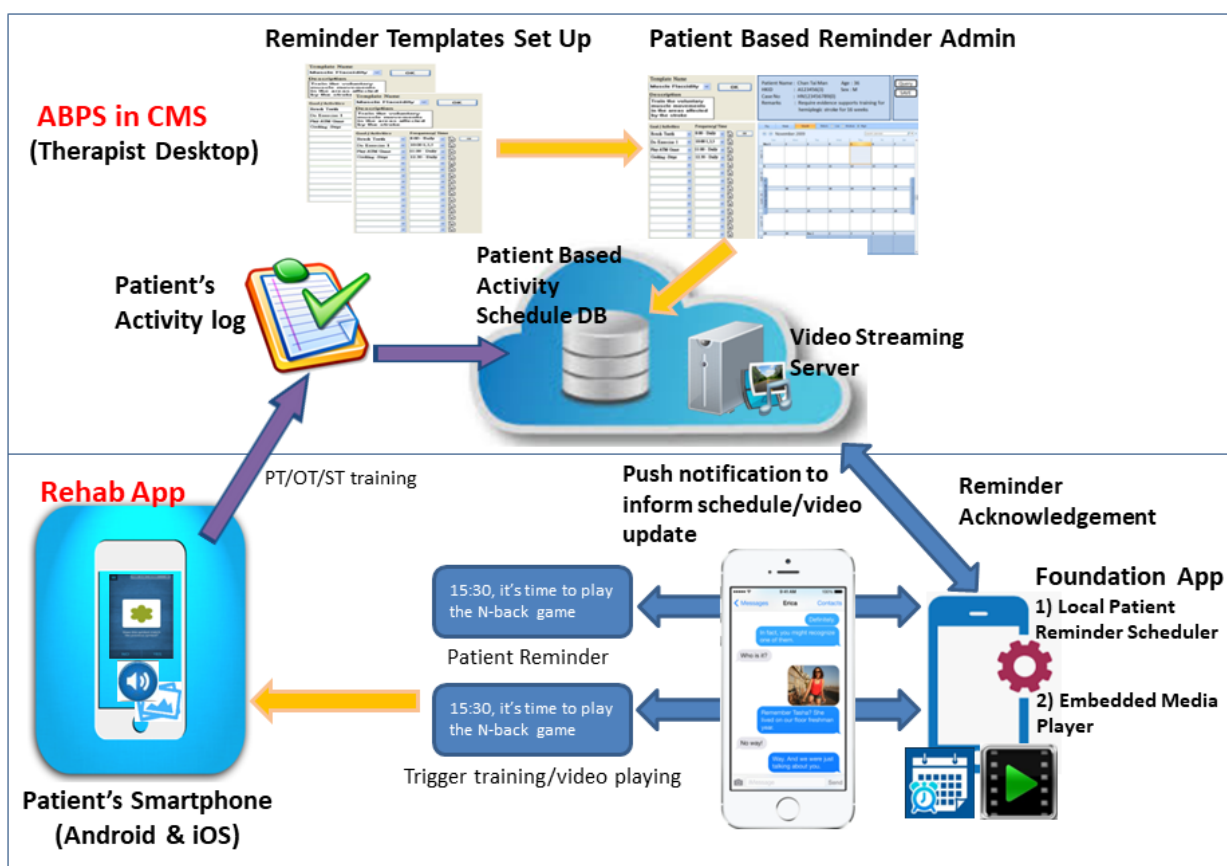
The Activity-Based Prescribing System

The Clinical Management System is the electronic medical record that all therapists in Hospital Authority use daily for clinical practice to disseminate health care information or clinical data and enhance patient care [35]. The activity-based prescribing system (ABPS) was specifically built to integrate into the Clinical Management System; the therapist needed no further log-ins and could view patient information, perform electronic documentation, and prescribe rehabilitation activities on the same platform. The Clinical Management System user password also contains information on the user's profession; therefore, the system only displayed prescription material specific to that profession. Page tabs built into the ABPS were designed to follow the workflow sequence of therapist (Multimedia Appendix 1): New activity, for videos and reminders selection; History, where all prescribed activities to the patient are displayed and therapist can choose to repeat an order if necessary; Template, which allowed the therapist to prescribe preset personal or departmental templates; Patient-Based Calendar, where the therapist can view all prescribed activities to patients at a glance (this allowed better distribution of patient schedule and prevents overlapping of prescription); Prescribed Activities, for allocating appropriate parameters to the prescription such as treatment period,

frequency, and timeslot; and Performance, for therapists to view the performance of a patient for prescribed training.

A therapist could complete a prescription with a few clicks. Altogether, 144 videos were incorporated into the ABPS. The ABPS was designed as a generic prescription platform to allow the future addition of training videos and reminders and future inclusion of more allied health professions.

The Rehabilitation App

Patients using tele-rehabilitation could be older adults who may have cognitive impairment or poor memory. Thus, the mobile app was designed to be simple and barrier-free. If a therapist prescribed a training video to a patient, a notification would be pushed to the app at the prescribed time. A swipe on the notification message could trigger the training video without having to log in to the app (Figure 2). The patient could also receive reminders—to wear a splint, wear a pressure garment, carrying out oral hygiene, or use walking aids—on a regular basis. Moreover, a daily and weekly activity page was included to facilitate the patient's viewing of their own rehabilitation schedule. Visual encouragement in the form of a thumbs-up was displayed on the app if the patient completed all prescribed training activities (Multimedia Appendix 1).

Figure 2. Push notification to trigger training video.

Client mobile received Push Notification on scheduled time

Patient Acknowledgement

Training Video Triggered without need to logon
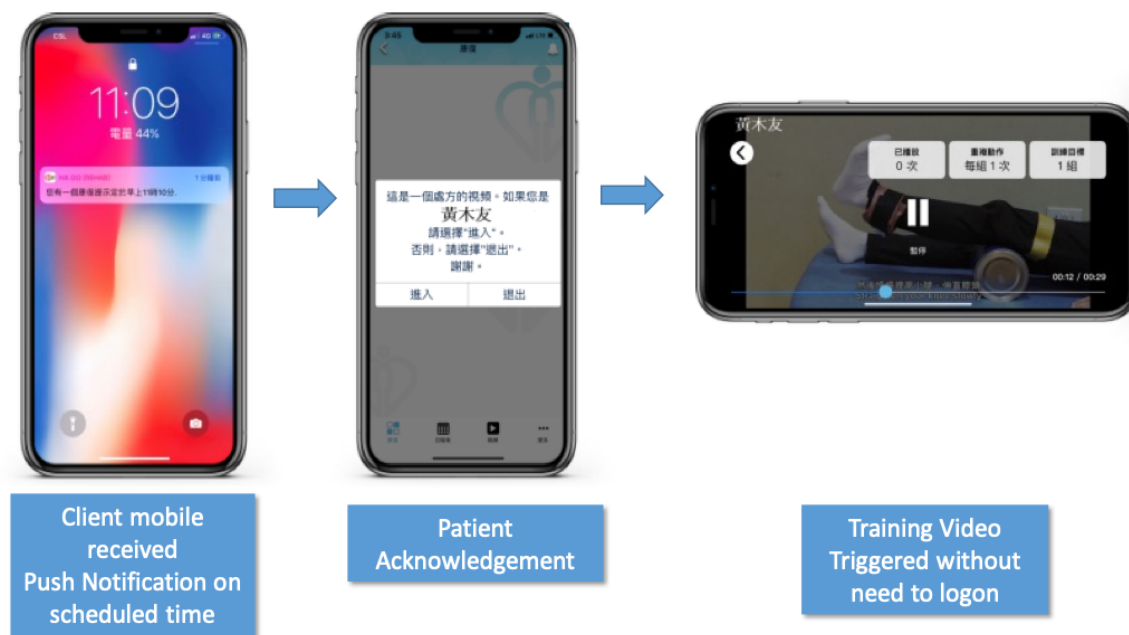
Staff Engagement Strategy and Technical Support

Occupational therapist, physiotherapist, and speech therapist staff committees were engaged to encourage therapists to participate in design, testing, and use. Senior management also expressed that tele-rehabilitation was a corporate direction, and therapists were encouraged to use this new technology. During the rollout of tele-rehabilitation, onsite support was provided to all hospitals. In addition, user guides and support hotline were provided to therapists and training videos were made

available to patients to ensure adequate support to both therapists and patients.

Privacy and Data Security

Privacy and data security were essential concerns in the development of tele-rehabilitation [7]. Data on the tele-rehabilitation platform were encrypted and stored on servers with restricted access. Security scanning was performed according to Hospital Authority standardization and regulation. Servers and databases were hardened for security, and firewall protection was also implemented. Even though the app was

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designed for easy access, this mode only allowed the patient to view training videos. If a patient needed to access their calendar or other app functions, full log in was still required. This approach balanced quick access to training with maintaining privacy. Moreover, push notifications on mobile phone was generic, without patient condition information or training details.
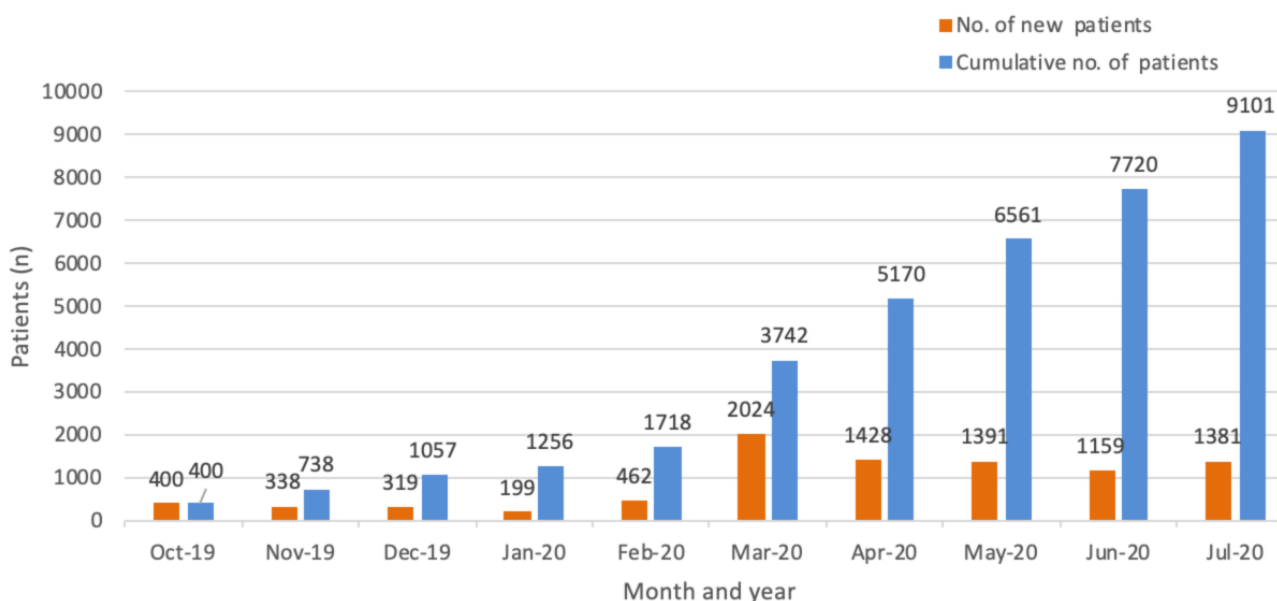
Data

We compared tele-rehabilitation use before and during the COVID-19 outbreak. Analysis before the outbreak analysis pertained to the period from October 2019 to January 2020, and analysis during outbreak period analysis pertained to the period from February 2020 to July 2020.

We collected 5 outcomes: throughput, the prescription rate of tele-rehabilitation; patient demographics; patient conditions for which tele-rehabilitation was prescribed; utilization rates by occupational therapists, physiotherapists, and speech therapist; and staff and patient satisfaction.

Satisfaction surveys were prepared and forwarded to both therapists and patients for collecting their opinion on the Rehabilitation App. The format of the surveys was discussed in the focus group. Therapists suggested that the surveys should be simple and require only a short time to complete. The survey for the therapists consisted of 8 questions while the survey for patients consisted of 4 questions. A 5-point scale was use in the survey (1, strongly disagree; 2, disagree; 3, neutral; 4, agree; 5, strongly agree). A prompt was shown on ABPS 30 days after the therapist started prescribing with the platform. The prompt contained a reminder to complete the survey. For patients, 7 days before their prescribed rehabilitation activity ended, a prompt was shown in Rehabilitation App to invite the patient to complete the survey.

Statistical Analysis

Patient demographic, workforce, and patient condition variables were nonparametric categorical data; therefore, chi-square analysis was used. P values less than .05 were statistically significant. When significance was found, the adjusted residual value was calculated. Statistical significance was set as <-1.96 and >1.96 (95% confidence interval). All data were analyzed using SPSS statistical software (version 26; IBM Corp).

Results

Impact of the COVID-19 Outbreak

Physiotherapy added 41 musculoskeletal training videos in early March and 15 additional musculoskeletal training videos in April. Speech therapy added 8 swallowing training videos in mid-March. Occupational therapy added 8 pulmonary training videos in early April. A total of 72 videos were added from February to April.

Throughput Analysis

The number of prescriptions per month showed a slightly decrease from October 2019 to January 2020. The number of new patients per month increased to 462 in February 2020 and spiked to 2024 in March 2020. The total number of patients prescribed accumulated to 9101 (Figure 3) by the end of July 2020. The prescription trend was stable in the months from May to July. Physiotherapists exhibited the highest increase in tele-rehabilitation prescriptions (Figure 4). Up until the end of July 2020, a total of 131995 training videos were prescribed, and the overall adherence rate of patients was 81.7% (107,840/131,995).

Figure 3. Patients prescribed tele-rehabilitation by month.

Figure 4. Tele-rehabilitation prescriptions per month by professions.
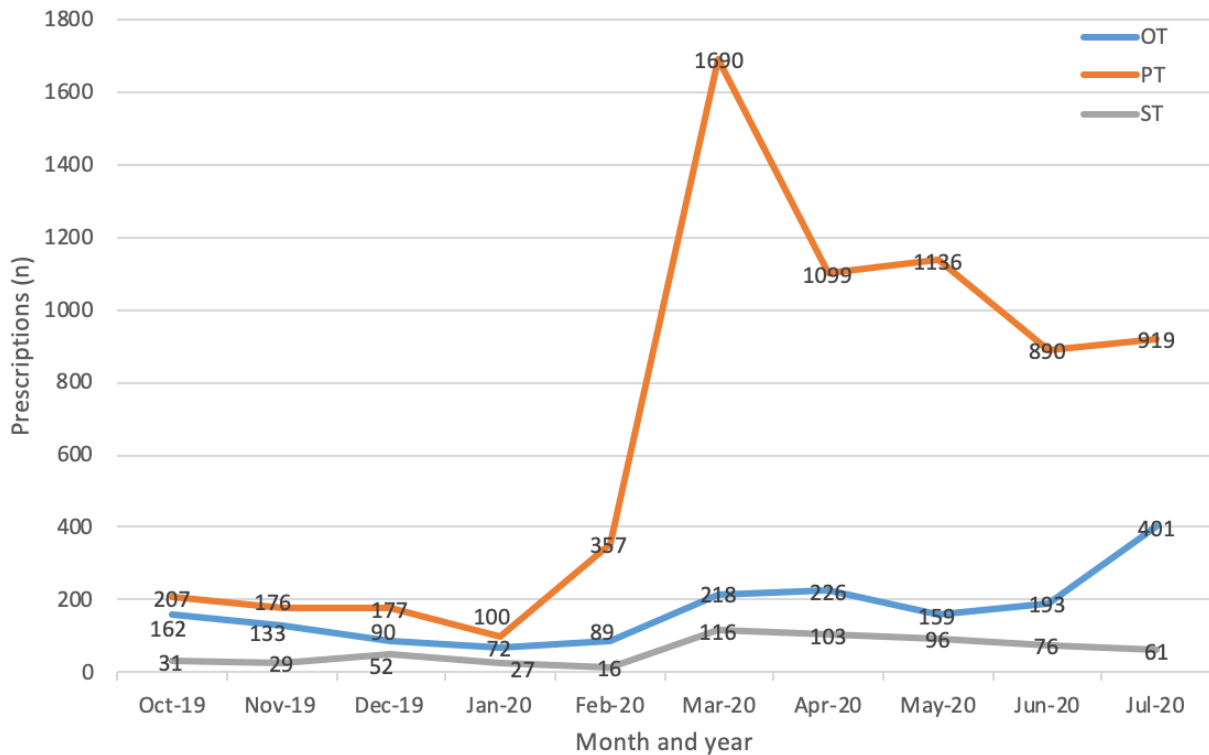
Patient Demographics

The Rehabilitation App was designed for adult patients, and the age of prescribed patients ranged from 18 to 106 years old. Age group analysis of patients revealed that before the outbreak, the age group with the highest prescription rate was 61 to 70 years (Figure 5). During the outbreak the age group with the highest prescription rate was 51 to 60 years. Before the outbreak, 48.8% of patients (610/1246) were below 60 years of age. After the outbreak, 55.2% of patients (4001/7845) were below 60 years of age (Table 1). There was no statistically significant difference in gender (P=.83) or age distribution (above and below 60 years: P=.36).

Figure 5. Before and during outbreak age distributions of patients prescribed tele-rehabilitation.
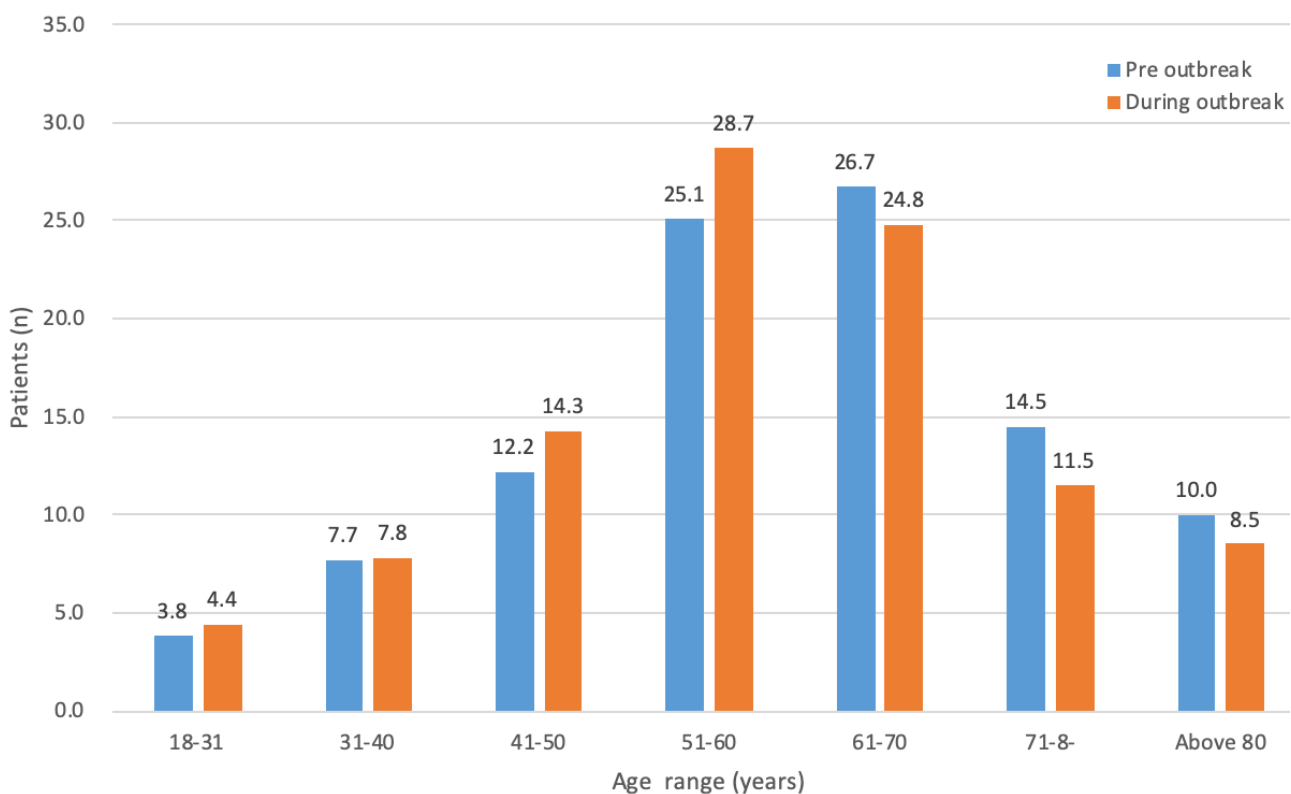
Table 1. Tele-rehabilitation patient demographics before and during the COVID-19 outbreak.

Characteristic	Before[a] (n=1246)	During[b] (n=7845)
Gender, n (%)		
Female	648 (52.0)	4158 (53.0)
Male	598 (48.0)	3687 (47.0)
Age (years), n (%)		
Below 60	610 (49)	4001 (55)
Above 60	636 (51)	3884 (45)
Age (years), mean (SD)	60 (15.5)	59 (16.2)
Age (years), median	61	60

[a]October 2019 to January 2020.

[b]February 2020 to July 2020.

Patient Conditions

Speech Therapy

Speech therapy had a relatively simple patient condition distribution; the main conditions were head and neck diseases, stroke, neurological conditions, neurosurgery, and cancer. Stroke and head and neck disease remained the largest case group for speech therapy throughout (Figure 6). The mean number of patients per month prescribed tele-rehabilitation before the outbreak was 35.5; whereas the mean increased to 117 during the outbreak (Table 2). There was increase in prescription per month (230%; ie, 117 – 35.5 / 35.5). Patient condition distributions before and during the outbreak did not significantly differ (P=.998).

**Figure 6.** Percentage distribution of patient conditions for speech therapy before and during the outbreak.
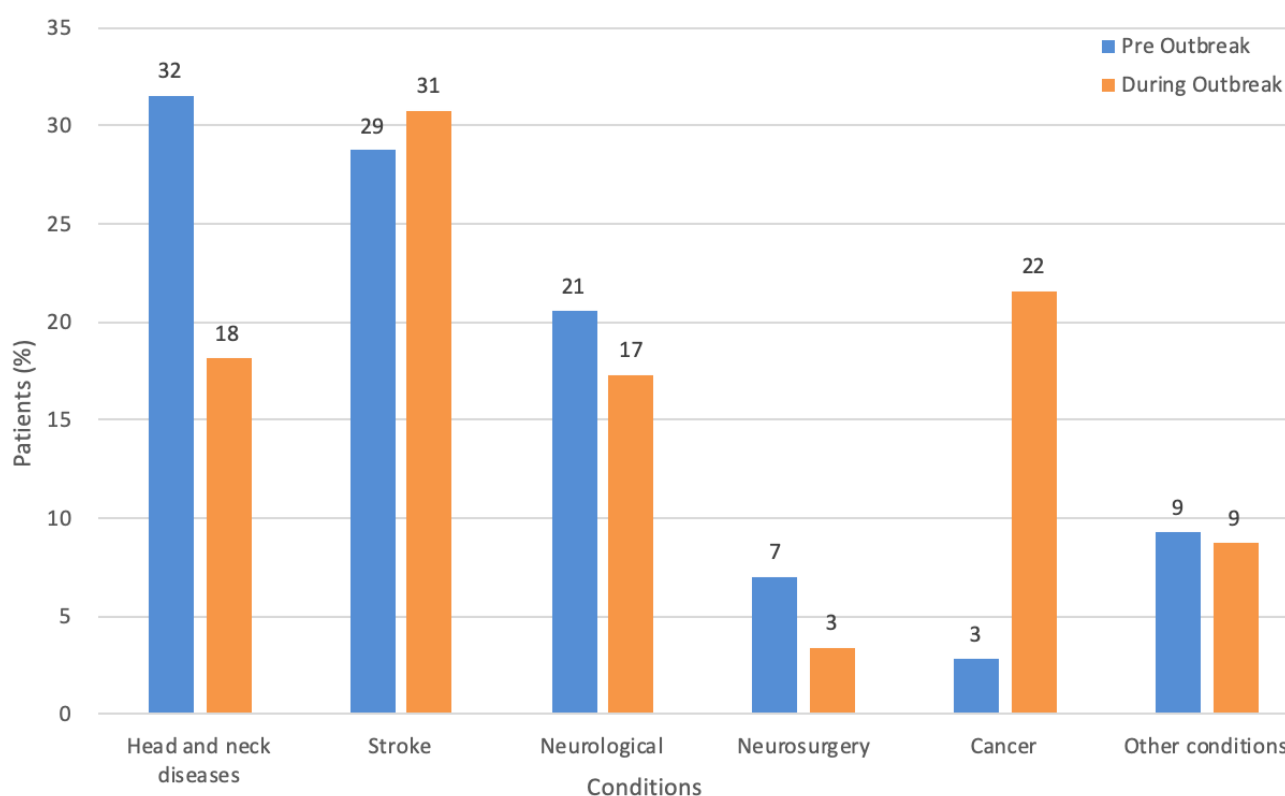
Table 2. Patient conditions for which speech therapy was prescribed before and during the COVID-19 outbreak.

Patient conditions	Before[a]		During[b]	
	Mean per month (SD)	%	Mean per month (SD)	%
Head and neck conditions	11.2 (3.4)	31.5	21.3 (5.9)	18.2
Stroke	10.2 (1.3)	28.7	36.0 (6.6)	30.7
Neurological	7.3 (1.2)	20.6	20.3 (6.1)	17.4
Neurosurgery	2.5 (0.8)	7.0	4.0 (2.4)	3.3
Cancer	1.0 (1.8)	2.8	25.3 (7.1)	21.6
Other conditions	3.3 (0.7)	9.3	10.3 (3.8)	8.8
Total	35.5	100	117.0	100

[a]October 2019 to January 2020.

[b]February 2020 to July 2020.

Occupational Therapy

Occupational therapy had several major patient condition groups including stroke, neurological conditions, weakness and deconditioning, pain and injury, cancer, and fractures (Figure 7). Stroke-related conditions constituted over 50% of total prescriptions (68/117.9), whereas fracture hip constituted only 2% (2.5/117.9). The mean per month before the outbreak was 118 patients, whereas the mean per month during the outbreak was 214 patients. There was increase in prescription per month (81.8%; ie, 214.3 – 117.9 / 117.9) (Table 3). Patient condition distributions before and during the outbreak did not significantly differ ($P=.93$).

Figure 7. Percentage distribution of patient conditions before and during outbreak for occupational therapy.
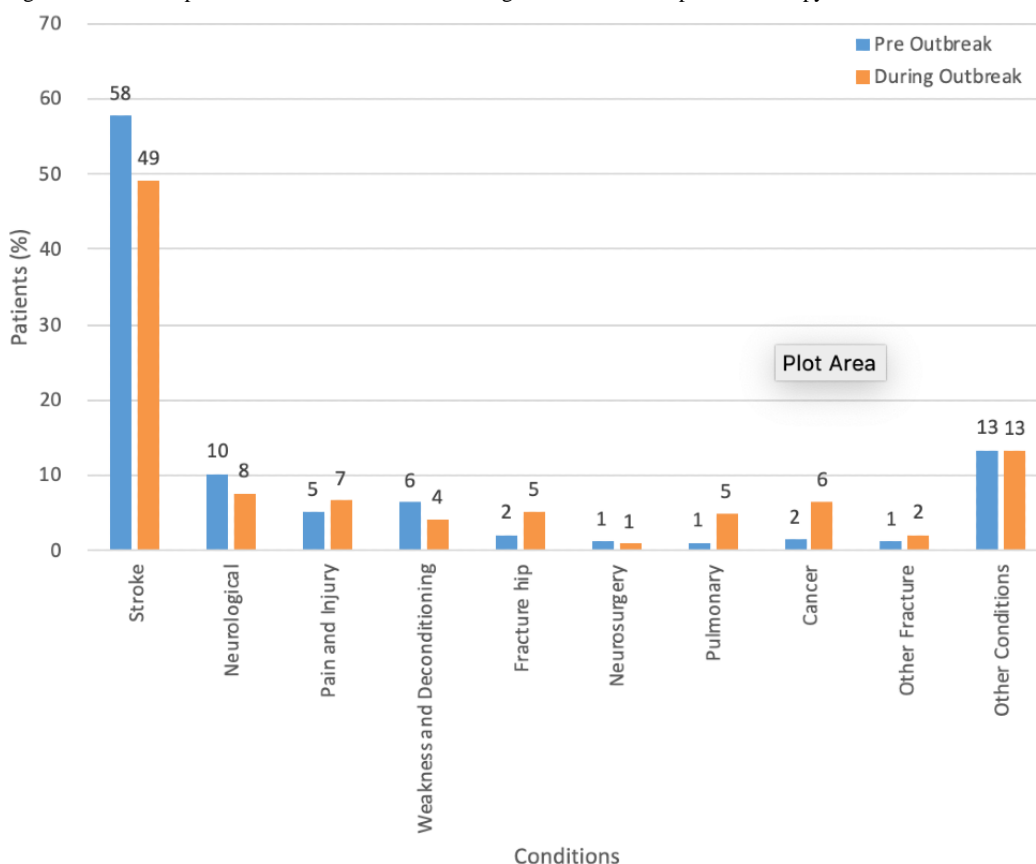
Table 3. Patient conditions for which occupational therapy was prescribed before and during the COVID-19 outbreak.

Patient conditions	Before[a]		During[b]	
	Mean per month (SD)	%	Mean per month (SD)	%
Stroke	68.0 (13.0)	57.7	105.3 (32.1)	49.1
Neurological	12.0 (1.9)	10.2	16.3 (6.6)	7.6
Pain and injury	6.0 (0.5)	5.1	14.2 (4.7)	6.6
Weakness and deconditioning	7.5 (0.8)	6.4	8.7 (3.9)	4.1
Fracture hip	2.5 (0.5)	2.1	11.0 (3.9)	5.1
Neurosurgery	1.5 (1.9)	1.3	1.8 (1.8)	0.8
Pulmonary	1.3 (0.5)	1.1	10.3 (6.8)	4.8
Cancer	1.8 (1.9)	1.5	13.8 (4.9)	6.4
Other fracture	1.5 (0.6)	1.3	4.5 (2.3)	2.1
Other conditions	15.8 (2.3)	13.4	28.3 (8.1)	13.2
Total	117.9	100	214.3	100

[a]October 2019 to January 2020.

[b]February 2020 to July 2020.

Physiotherapy

Physiotherapy had a diverse patient conditions distribution. There were several conditions including stroke, weakness and deconditioning, fracture hip, pain and injury, neurological conditions, and low back pain (Figure 8). The most prescribed condition before outbreak was stroke (20.3/173.9, 12%), whereas the most prescribed condition during the outbreak was lower back pain (138.5/1015.2, 14%). Other than clinical conditions related to frail older adult patients, hip fracture only constituted 3% (5/173.2) before the outbreak and 5% (53.2/1015.2) during the outbreak. There were many conditions related to musculoskeletal problems; *other conditions* comprised a large variety of musculoskeletal conditions including soft tissue problems and degenerative problems and occupied the highest percentage before and during the outbreak. The mean number of prescriptions per month before the outbreak was 174, and the mean increased to 1015 per month during the outbreak. The average number of prescription per month increased after the outbreak (484%; ie, 1015 – 174 / 174) (Table 4). There was a statistically significant difference between patient condition distributions before and during the outbreak (P=.04). There were statistically significant decreases in weakness and deconditioning (adjusted residual –2.5, 2.5) and neurological condition (adjusted residual –3.4, 3.4); (2) statistically significant increase in lower back pain (adjusted residual –2.9, 2.9), pain and injury (adjusted residual –2.2, 2.2), and neck pain (adjusted residual –2.1, 2.1). This was also demonstrated by the percentage change in distribution in these conditions.

Figure 8. Percentage distribution of patient conditions before and during outbreak for physiotherapy.
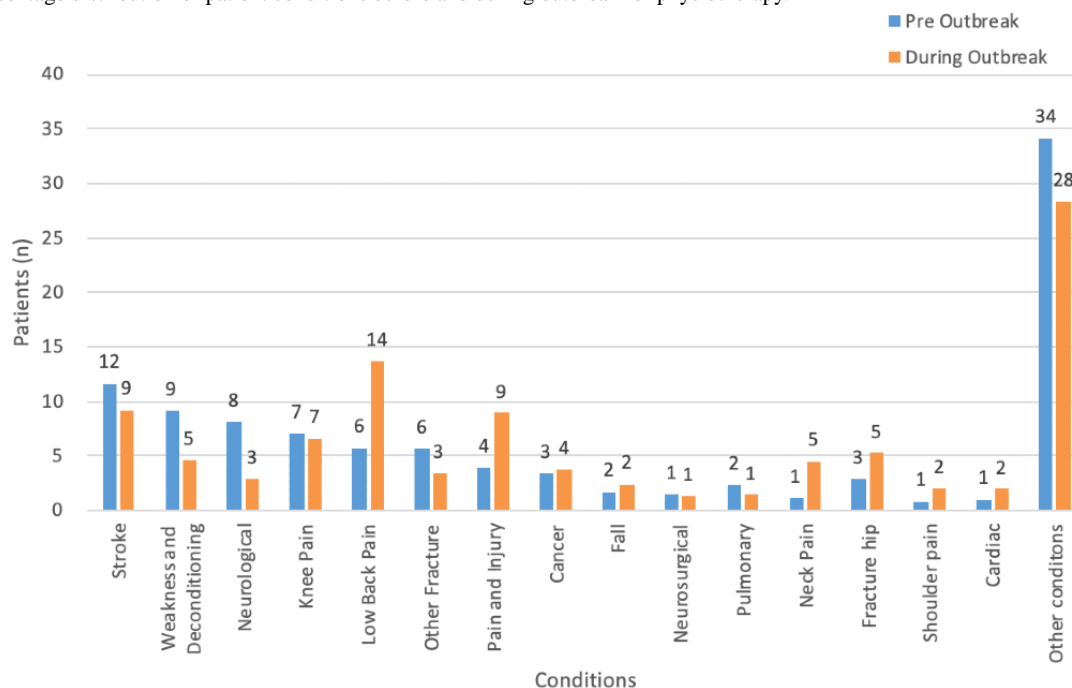
Table 4. Patient conditions for which physiotherapy was prescribed before and during the COVID-19 outbreak.

Patient conditions	Before[a]		During[b]		Adjusted residual value[c]
	Mean per month (SD)	%	Mean per month (SD)	%	
Stroke	20.3 (6.0)	11.7	93.3 (13.4)	9.2	−0.9, 0.9
Weakness and deconditioning	15.8 (2.7)	9.1	46.8 (4.6)	4.6	−2.5, 2.5[c]
Neurological	14.0 (2.9)	8.0	29.2 (9.9)	2.9	−3.4, 3.4[c]
Knee pain	12.3 (2.7)	7.1	67.0 (39.3)	6.6	−0.1, 0.1
Lower back pain	10.0 (5.5)	5.7	138.5 (62.8)	13.7	−2.9, 2.9[c]
Other fracture	9.8 (4.2)	5.6	34.2 (16.6)	3.4	−1.5, 1.5
Pain and injury	6.8 (3.9)	4.0	90.3 (45.1)	8.9	−2.2, 2.2[c]
Cancer	5.8 (2.7)	3.3	37.7 (10.4)	3.7	−0.2, 0.2
Fall	3.0 (1.2)	1.7	24.2 (6.5)	2.4	−0.5, 0.5
Neurosurgical	2.5 (2.1)	1.4	13.3 (8.3)	1.3	−0.5, 0.5
Pulmonary	4.0 (0.5)	2.3	14.3 (5.9)	1.4	−0.9, 0.9
Neck pain	2.0 (1.1)	1.1	46.0 (27.0)	4.5	−2.1, 2.1[c]
Fracture hip	5.0 (1.9)	2.9	53.2 (13.5)	5.2	−1.3, 1.3
Shoulder pain	1.5 (0.7)	0.9	20.3 (5.5)	2.0	−0.8, 0.8
Cardiac	1.8 (1.1)	1.0	19.5 (6.0)	1.9	−0.8, 0.8
Other conditions	59.3 (20.4)	34.1	287.3 (63.3)	28.3	−1.5, 1.5
Total count	173.9	100	1015.2	100	N/A[d]

[a]October 2019 to January 2020.

[b]February 2020 to July 2020.

[c]Statistically significant 95% confidence interval (<−1.96 and >1.96).

[d]N/A: not applicable.

Workforce

In February 2020, there were a total of 907 occupational therapists, 1177 physiotherapists, and 112 speech therapists employed in Hospital Authority, and 1112 therapists (372 occupational therapists, 635 physiotherapists, and 105 speech therapists) prescribed tele-rehabilitation to patients, which constituted 50.6% (1112/2196) of the total workforce. Physiotherapy and occupational therapy had a 3-tier rank structure (rank I, rank II, and senior). Rank II was the entry rank, and rank I was the middle rank. Speech therapy had a 2-tier rank structure (basic and senior). Speech therapists had the highest overall prescription rate (speech therapists: 105/112, 93.8%; physiotherapists: 635/1177, 54.0%; occupational therapists: 372/907, 41.0%). There were statistically significant differences in prescriptions by rank for occupational therapists (P=.001) and physiotherapists (P<.001), and no statistically significant difference for speech therapists (P=.45). Further analysis by adjusted residual value demonstrated that there were differences in prescriptions between occupational therapist II and senior occupational therapist and between physiotherapist II, physiotherapist I, and senior physiotherapist (Table 5).

Table 5. Analysis of prescription according to therapist rank.

Rank	Total workforce	Prescribed tele-rehabilitation	Percentage of workforce	Adjusted residual value	P value
Occupational therapy					.001
Occupational therapist II	442	201	45.5	–2.7, 2.7	
Occupational therapist I	389	154	39.6	–0.8, 0.8	
Senior occupational therapist	76	17	22.4	–3.5, 3.5	
Physiotherapy					<.001
Physiotherapist II	554	350	63.2	–6.0, 6.0	
Physiotherapist I	524	266	50.8	–2.0, 2.0	
Senior physiotherapist	99	19	19.2	–7.3, 7.3	
Speech therapy					.45
Speech therapist	104	97	93.3	–0.8, 0.8	
Senior speech therapist	8	8	100	–0.8, 0.8	

Therapist and Patient Satisfaction

Of 2196 therapists, 111 therapists completed the survey; the response rate was 5.2%. Overall satisfaction toward the Rehabilitation App was rated as 3.7 (Table 6). It was opined, by therapists, that they needed to use a considerable amount of time to instruct and assisted patients to install the Rehabilitation App. The preparation work was regarded as increased workload to therapists. In addition, several meetings with therapists revealed that they required an expanded video library in order to prescribe training to patients with a variety of conditions. The survey showed that therapists found the Rehabilitation App to be effective for patients to continue rehabilitation in a home setting.

Table 6. Therapist survey scores.

Therapist questions	Score (n=111), mean
The installation procedures are easy to administer	3.5
The training app is well organized.	3.8
The training app is user-friendly	3.6
The content of the app meets the patient's training need	3.7
The app can enhance patient's treatment frequency apart from regular treatment	3.8
The app could facilitate you to prescribe the home program	4.2
The app could assist you in treatment planning	3.8
Overall, you satisfy with the training app.	3.7

The response from the patient's side was very positive. The response rate was 28.8%, with 2623 of 9101 patients completing the survey. Overall satisfaction rate was rated as 4.2 (Table 7).

Several commendation letters were received regarding the Rehabilitation App, and most patients found the app to be user friendly and helpful.

Table 7. Patient survey scores.

Patient questions	Score (n=2623), mean
The training app is easy to use.	4.2
The training app improves my participation in the home program.	4.2
The training app is helpful for my rehabilitation.	4.1
Overall, I am satisfied with the training app.	4.2

Discussion

Principal Results

Use of tele-rehabilitation increased remarkably during the COVID-19 pandemic. Physiotherapy had the highest number of prescriptions. Tele-rehabilitation was mostly prescribed to patients between 51 and 70 years of age. Patients reported a high level of satisfaction. Over 50% of the total workforce prescribed tele-rehabilitation to patients (1112/2196, 50.6%). Originally, tele-rehabilitation was designed to treat patients with stroke, patients with hip fracture, and older adults with frailty. Our study showed that tele-rehabilitation can be used for a much wider spectrum of patient conditions. The generic design of the tele-rehabilitation was able to expand training content and cope with the service demand for rehabilitation during the outbreak period.

Utilization of Tele-rehabilitation Before and During Outbreak

Tele-rehabilitation utilization reached a peak in March 2020 during the first wave of outbreak in Hong Kong. Tele-rehabilitation use dropped from 2024 new patients in March to approximately 1300 per month from April to July. The stable trend indicated that tele-rehabilitation was used irrespective of number of confirmed COVID-19 cases. Continuous monitoring is needed to study the sustainability of utilization and especially during the postpandemic phase.

Our study showed that there was no difference in distribution between patients above or below 60 years old. This finding echos those of Crotty et al [34]—the age of patient was not really a barrier for the acceptance of tele-rehabilitation. For the 2623 patients who responded to the survey, overall satisfaction score for the app was a mean of 4.2 out of 5. Moreover, the overall adherence rate for tele-rehabilitation in our study was recorded at a satisfactory level of 81.7 % (107,840/131,995). This provided a reliable reflection of the high acceptance of tele-rehabilitation by patients. On the other hand, only 111 therapists responded to the survey, and the overall satisfaction score of therapists for the app was a mean of 3.73 out of 5. The design of the survey questions for therapists had a serious shortcoming in that it focused on the app rather than on the ABPS. It was inappropriate for therapists to provide opinions on using the app. A more comprehensive and appropriately designed survey would be needed to reflect the opinion of therapists on ABPS.

Analysis of workforce data demonstrated that 50.6% of the total workforce (1112/2196) prescribed tele-rehabilitation. There was significant difference in prescription rate between basic and senior ranks in occupational therapy ($P=.001$) and physiotherapy ($P<.001$), and there was an apparent difference in the prescription rate of tele-rehabilitation among the 3 allied health professions (occupational therapist: 372/907, 41.0%, physiotherapist: 635/1177, 54%, speech therapist: 105/112, 93.8%). Speech therapy had the most severe disruption in service during the outbreak, which could be attributed to the high rate of prescription. There was a highest absolute number of prescriptions among physiotherapist. This was attributable to fact that physiotherapy had the largest workforce, and there was extensive use of tele-rehabilitation for musculoskeletal conditions. The differences, however, also raised the question of whether tele-rehabilitation was equally suitable to different allied health services. For example, tele-rehabilitation in the form of a video may not fit activities of daily living training, which requires the use of tools and equipment. Whereas for physical training prescribed by physiotherapist and oral-motor training prescribed by speech therapists, video training is a suitable format.

Analysis of clinical conditions revealed that there was an increase in prescriptions for patients after stroke during the outbreak period (1.55-fold increase in occupational therapy, 4.60-fold increase in physiotherapy, and 3.53-fold increase in speech therapy). These findings aligned well with the initial goals of the tele-rehabilitation platform. However, we noticed that hip fracture ranked rather low in the prescription rate for both physiotherapists and occupational therapists which was surprisingly not aligned with the objectives of the platform's development. On the other hand, both physiotherapists and occupational therapists prescribed tele-rehabilitation for a broad spectrum of clinical conditions. There was a significant increase in prescriptions to musculoskeletal conditions of lower back pain (adjusted residual –2.9, 2.9), neck pain (adjusted residual –2.1, 2.1), and pain and injury (adjusted residual –2.2, 2.2). The results demonstrate that tele-rehabilitation is indicated for a broad spectrum of patient conditions.

Tele-rehabilitation System Design

A generic design was adopted for both the ABPS and mobile app. This facilitated rapid expansion of training content. Previous studies [10,19,21,26,31] on tele-rehabilitation often require the use of sophisticated communication tools, equipment, or software. During the COVID-19 crisis, the use of off-the-shelf technology and the expansibility of our tele-rehabilitation design enabled provision of rehabilitation service to a large amount of patients. In addition, Hong Kong has one of the highest smartphone ownership rates in Asia—for Hong Kong citizens over 10 years old, 88% of females and 91% of males own a smartphone [36]. This high ownership of smartphones could be a facilitating factor for our tele-rehabilitation platform use.

Opportunities and Challenges

The COVID-19 pandemic has altered health care delivery globally. Severe restrictions such as social distancing and the suspension of rehabilitation services were enacted to prevent spread of disease. The World Health Organization recommended postponing treatments that were not considered urgent in order to ensure safety, while still guaranteeing the essential rehabilitation services [37]. The pandemic has catalyzed the rapid adoption of telehealth worldwide [38]. Tele-rehabilitation is promising for overcoming service disruption during the outbreak [39,40]. Implementation of tele-rehabilitation has been recommended by different allied health professions [39-42].

Through the advent of technology, faster internet connection, cheaper smart devices (smartphones and tablets), and new software being available, tele-rehabilitation is able to offer many benefits. However, there are challenges ahead if tele-rehabilitation is to be used extensively in the future. For example, the use of tele-rehabilitation is a paradigm shift for therapists from conventional face-to-face interventions. During the outbreak, there was a rapid increase in the number of therapists who needed to prescribe tele-rehabilitation. Consequently, training and accrediting staff to use tele-rehabilitation became essential. A *train the trainer* model can be a feasible to allow rapid staff development to enable trained staff to onboard others in the use of tele-rehabilitation [39]. There was concern from Hospital Authority that the number of infections from the pandemic may fluctuate and the pandemic could last for some time and that there would be high utilization of tele-rehabilitation. Consequently, training and support for therapists using tele-rehabilitation was considered important. As many allied health professions are predominantly hands-on and skill-based professions, the lack of physical contact with patients is a hurdle for tele-rehabilitation utilization. Thus, essential infrastructure enhancements for future tele-rehabilitation development include patient evaluation, assessment, physiological monitoring, and education [39].

Moreover, legislation and payment arrangement should be in place to facilitate tele-rehabilitation delivery [38,39].

The COVID-19 pandemic will not affect the acute outbreak period alone but may also create a serious backlog for rehabilitation in the postpandemic recovery period, which is referred to as "care debt [38]." To transform tele-rehabilitation from crisis mode during pandemic to a sustainable mode after outbreak requires clear deliberation and planning.

Limitations

This observational study has a number of limitations. This study only reports outcomes of tele-rehabilitation utilization before and during outbreak periods. It does not cover the clinical effectiveness of tele-rehabilitation to patients; this requires additional well-powered clinical studies. The Unified Theory of Acceptance and Use of Technology [12] is used as a guiding framework for development of the tele-rehabilitation. It is a limitation that this model is not used to evaluate the acceptance of this new technology. The design of the survey questions also had serious shortcoming. The study period was relatively short, and sustained utilization of tele-rehabilitation requires a longer duration study. More meaningful information can be gathered if the study is extended to the period when COVID-19 pandemic is over.

Conclusions

The COVID-19 pandemic has seriously affected rehabilitation service delivery. Our study has shown that a tele-rehabilitation platform was used extensively and effectively during the outbreak period to mitigate service disruption. In addition to the original targeted conditions (stroke and hip fracture), tele-rehabilitation was prescribed for a large variety of clinical conditions. The tele-rehabilitation platform, though it cannot replace all face-to-face rehabilitation services, has demonstrated its potential during the COVID-19 crisis and has promising potential to become a sustainable service delivery model.

Conflicts of Interest

None declared.

Multimedia Appendix 1
Supplementary material.
[DOCX File , 721 KB - rehab_v8i3e19946_app1.docx]

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Abbreviations

ABPS: activity-based prescribing system

XSL•FO

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<u>Corrigenda and Addenda</u>

Correction: Homes of Stroke Survivors Are a Challenging Environment for Rehabilitation Technologies

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Related Article:

Correction of: https://rehab.jmir.org/2021/2/e12029

In "Homes of Stroke Survivors Are a Challenging Environment for Rehabilitation Technologies" (JMIR Rehabil Assist Technol 2021;8(2):e12029) the authors noted three errors.

The Acknowledgments section of the paper has been updated to effectively acknowledge the work of the broader Motivating Mobility team. In the originally published version, the Acknowledgements section read as follows:

> *This work was supported by the Engineering and Physical Sciences Research Council (grants EP/F00382X/1, EP/F03038X/1, and EP/M000877/1).*

This has been updated to:

> *This work was supported by the Engineering and Physical Sciences Research Council (grants EP/F00382X/1, EP/F03038X/1, and EP/M000877/1). Our article reflects on the body of work produced by the Motivating Mobility team from 2007 to 2010. The authors would like to acknowledge the contribution of all team members to this body of work. Motivating Mobility was a collaboration between the University of Sussex (Lesley Axelrod, Madeline Balaam, Eric Harris, Geraldine Fitzpatrick), the University of Southampton (Ruth Turk, Ann-Marie Hughes, Jane Burridge), Sheffield Hallam University (Anna Wilkinson, Sue Mawson), the University of Oxford (Nour Shublaq, Penny Probert Smith), the University of Nottingham (Stefan Rennick-Egglestone, Tom Rodden), and the University of Dundee (Thomas Nind, Ian Ricketts).*

The captions of 3 figures have been updated to clarify that the images were drawn from previous articles cited in the paper. The following text has been added to the original caption of Figures 1 and 2:

> *First published in the study by Axelrod et al [26].*

The following text has been added to the original caption of Figure 4:

> *First published in the study by Balaam et al [30].*

In the originally published paper, the following sentence was included in the "Challenge 1: Identifying a Location for a Rehabilitation Technology" section:

> *Early in Motivating Mobility, we conducted a photographic study of the homes of stroke survivors recruited by the project.*

The text may have inadvertently created the impression that one author (SR-E) was involved in a Motivating Mobility study for which he was in fact not involved. For clarity, this sentence has been updated to:

> *Early in Motivating Mobility, a photographic study of the homes of stroke survivors was conducted [26].*

The correction will appear in the online version of the paper on the JMIR Publications website on August 16, 2021, together with the publication of this correction notice. Because this was made after submission to PubMed, PubMed Central, and other full-text repositories, the corrected article has also been resubmitted to those repositories.

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