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Association Between Therapeutic Alliance and Outcomes Following Telephone-Delivered Exercise by a Physical Therapist for People With Knee Osteoarthritis: Secondary Analyses From a Randomized Controlled Trial

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Abstract

Background: The therapeutic alliance between patients and physical therapists has been shown to influence clinical outcomes in patients with chronic low back pain when consulting in-person. However, no studies have examined whether the therapeutic alliance developed between patients with knee osteoarthritis and physical therapists during telephonic consultations influences clinical outcomes.

Objective: This study aims to investigate whether the therapeutic alliance between patients with knee osteoarthritis and physical therapists measured after the second consultation is associated with outcomes following telephone-delivered exercise and advice.

Methods: Secondary analysis of 87 patients in the intervention arm of a randomized controlled trial allocated to receive 5 to 10 telephone consultations with one of 8 physical therapists over a period of 6 months, involving education and prescription of a strengthening and physical activity program. Separate regression models investigated the association between patient and therapist ratings of therapeutic alliance (measured after the second consultation using the Working Alliance Inventory Short Form) and outcomes (pain, function, self-efficacy, quality of life, global change, adherence to prescribed exercise, physical activity) at 6 and 12 months, with relevant covariates included.

Results: There was some evidence of a weak association between patient ratings of the alliance and some outcomes at 6 months (improvements in average knee pain: regression coefficient −0.10, 95% CI −0.16 to −0.03; self-efficacy: 0.16, 0.04-0.28; global improvement in function: odds ratio 1.26, 95% CI 1.04-1.39, and overall improvement: odds ratio 1.26, 95% CI 1.06-1.51; but also with worsening in fear of movement: regression coefficient −0.13, 95% CI −0.23 to −0.04). In addition, there was some evidence of a weak association between patient ratings of the alliance and some outcomes at 12 months (improvements in self-efficacy: regression coefficient 0.15, 95% CI 0.03-0.27; global improvement in both function, odds ratio 1.19, 95% CI 0.03-1.37; and pain, odds ratio 1.14, 95% CI 1.01-1.30; and overall improvement: odds ratio 1.21, 95% CI 1.02-1.42). The data suggest that associations between therapist ratings of therapeutic alliance and outcomes were not strong, except for improved quality of life at 12 months (regression coefficient 0.01, 95% CI 0.0003-0.01).

Conclusions: Higher patient ratings, but not higher therapist ratings, of the therapeutic alliance were weakly associated with improvements in some clinical outcomes and with worsening in one outcome. Although the findings suggest that patients who perceive a stronger alliance with their therapist may achieve better clinical outcomes, the observed relationships were generally weak and unlikely to be clinically significant. The limitations include the fact that measures of therapeutic alliance have not been
validated for use in musculoskeletal physical therapy settings. There was a risk of type I error; however, findings were interpreted on the basis of clinical significance rather than statistical significance alone.

**Trial Registration:** Australian New Zealand Clinical Trials Registry ACTRN12616000054415; https://www.anzctr.org.au/Trial/Registration/TrialReview.aspx?id=369204

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**KEYWORDS**
osteoarthritis; physiotherapy; physical therapy; tele-rehabilitation; telephone; therapeutic alliance; exercise; knee; pain

**Introduction**

**Background**

Knee osteoarthritis (OA) is highly prevalent and leading cause of functional limitation in older adults [1,2]. Given that there is no cure for OA, long-term self-management of the condition aims to reduce joint pain and improve physical function and quality of life. All current clinical guidelines recommend education, exercise, and if appropriate, weight loss [3-6]. Physical therapists are one of the most common providers of exercise management for people with OA [7] and traditionally, consultations occur in-person at a physical therapy clinic. However, there is a growing body of literature to support the safety and effectiveness of tele-rehabilitation, where physical therapists and patients consult remotely using telecommunication technologies, such as video conferencing or telephone [8-10]. Accordingly, tele-rehabilitation, as the mode of delivery of physical therapy services, is increasingly being advocated and implemented in Australia [11], the United Kingdom [12], and the United States [13,14].

An important aspect of health care is the strength of the relationship developed between the patient and the health professional. This relationship, known as the therapeutic alliance, is conceptualized as a sense of collaboration, warmth, and support between a patient and clinician [15], and it focuses on 3 elements of the relationship: (1) agreement on goals; (2) agreement on tasks; and (3) personal bond. Extensive research in psychotherapy settings (eg, patients recovering from schizophrenia, poor mental health, drug use) has demonstrated that a strong therapeutic alliance between patients and their therapists can positively influence satisfaction with care, quality of life, psychological well-being, symptom improvement, and treatment adherence [16-19]. There is emerging evidence that therapeutic alliance is also important in musculoskeletal rehabilitation. Two recent systematic reviews found evidence that a therapeutic alliance in people with chronic musculoskeletal pain (eg, chronic low back pain) was associated with clinical outcomes from treatment, including improvement in pain and function [20,21]. In contrast, another systematic review reported that the small number of studies available, failed to provide evidence of a strong relationship between therapeutic alliance and improvement in pain [22]. None of the studies cited in any of these three reviews evaluated the therapeutic alliance during tele-rehabilitation consultations. In addition, evidence suggests that therapeutic alliance is associated with better adherence to prescribed exercise. A cross-sectional study of 87 participants with musculoskeletal injuries found that the strongest predictor of adherence to home-based rehabilitation exercises was the therapeutic alliance between patients and the physical therapists treating them during in-person consultations [23].

**Rationale for This Study**

Most existing studies evaluating relationships between therapeutic alliance and outcomes of physical therapy practice have focused on in-person consultations between patients and therapists. Thus, it is not clear if findings from such studies can be generalized to telephone-delivered models of physical therapy care, where patients and physical therapists have no physical or visual contact. Our research provides some evidence from qualitative studies that physical therapists and patients with OA perceive a strong alliance when consulting via video [24] and telephone [25,26]. In addition, we found that both patient and physical therapist ratings of the therapeutic alliance using a validated measure [27] were high, when consulting via telephone and generally in agreement with each other [28]. However, the relationship between therapeutic alliance and clinical outcomes from telephone-delivered physical therapy care remains unexplored. Thus, the aim of this study was to investigate whether the therapeutic alliance between patients and physical therapists is associated with self-reported clinical outcomes (including pain, function, fear of movement, quality of life, exercise adherence, treatment satisfaction, physical activity) at 6 and 12 months following telephone-delivered exercise and advice for people with knee OA.

**Methods**

**Design**

This exploratory study used data collected from physical therapists and patients in the intervention arm of a randomized controlled trial (RCT; Australian New Zealand Clinical Trials Registry (ANZCTRN) 12616000054415), which evaluated the effectiveness of incorporating physical therapist-delivered exercise advice and support into an existing musculoskeletal telephonic service delivered by nurses [10,29]. The funders played no role in the design, conduct, or reporting of this study. All participants provided written informed consent, and the institutional ethics committee approved the study.

**Patients**

The intervention arm of the RCT included 87 randomized patients with knee OA. Inclusion criteria were meeting the National Institute for Health and Care Excellence OA clinical criteria (aged 45 years or over, with activity-related joint pain and morning stiffness ≤30 min) [5], an average knee pain of ≥4 on an 11-point numeric rating scale, and a history of knee pain

http://rehab.jmir.org/2021/1/e23386/
for at least three months. The exclusion criteria have been published elsewhere [29]. Patients for the RCT were recruited from rural, regional, and metropolitan areas of Australia using advertisements on social media, on the radio, and in newspapers, through community organizations, and using previous volunteer databases.

**Physical Therapists**

A total of 8 physical therapists were recruited in Victoria, Australia, to deliver the intervention for the trial. Selection criteria included a physical therapy qualification, at least two years of musculoskeletal professional experience, and current Australian registration to practice. Before the commencement of the trial, the physical therapists underwent a 2.5-day training program in the delivery of person-centered care and behavior change (delivered by HealthChange Australia) [30,31]. This involved the use of a set of practice principles to foster effective communication, techniques to identify and address barriers to behavior change, and a framework to guide decision making.

**Intervention**

Details of the RCT have been published [29], including trial findings [10]. Patients in the intervention arm of the trial initially received a telephone call from a nurse as part of an existing musculoskeletal help line, where they received general information and advice about OA. Patients then received between 5 and 10 telephonic consultations from one of the eight physical therapists over a 6-month period (the same physical therapist provided all the consultations for each of their patients). During the initial consultation (approximately 40 min in length), the physical therapists helped increase patient knowledge and understanding of knee OA and the benefits of exercise. They worked with patients to devise goals and action plans that involved structured home-based strengthening exercise programs and/or physical activity plan. During follow-up consultations (approximately 20 min in length; the precise number of consultations was negotiated between the patients and their physical therapists), the physical therapists adjusted the program as necessary, while providing support using person-centered practice principles and behavior change techniques to help build patient confidence in their ability to undertake and adhere to an exercise program.

Patients were provided with a study folder containing information about OA and management, exercise instructions and access to a study website containing video demonstrations of each exercise. Patients were provided with three exercise resistance bands for home exercises.

**Outcome Measures**

Outcome measures (collected at baseline, 6, and 12 months) in the RCT that were included in this secondary analysis were as follows:

1. Overall average knee pain in the past week (measured with a numeric rating scale ranging from 0 indicating no pain to 10, indicating the worst pain possible).
2. Physical function (measured using the Western Ontario and McMaster Universities Osteoarthritis Index [32] with scores ranging from 0 to 68, with lower scores indicating better function).
3. Self-efficacy (measured using the Arthritis Self-Efficacy Scale [33], total scores ranging from 3 to 30, with higher scores indicating greater self-efficacy).
4. Quality of life (using the assessment of quality of life [AQoL] instrument [34], with scores from -0.04 to 1.00, higher scores indicating better quality of life).
5. Global changes at 6 and 12 months (overall, pain, and function) via 7-point scales (terminal descriptors much worse to much better), as well as change in physical activity (descriptors much less to much more). Scores were dichotomized into 1 (improved or increased; those indicating moderately better or more or much better or more) and 0 (not improved or increased; those indicating much worse, moderately worse, slightly worse, or no change).
6. Satisfaction with care collected at 6 and 12 months via a 7-point scale (terminal descriptors extremely unsatisfied to extremely satisfied). Scores were dichotomized into 1 (satisfied; those indicating moderately satisfied or extremely satisfied) and 0 (not satisfied; those indicating extremely unsatisfied, moderately unsatisfied, slightly unsatisfied, or neither satisfied or unsatisfied).
7. Physical therapist-rated patient adherence to home exercise program collected at 6-months via an 11-point scale (terminal descriptors 0=not at all to 10=completely as instructed), only collected at 6 months.
8. Self-rated adherence to (a) prescribed exercises and (b) physical activity plan via an 11-point scale (terminal descriptors 0=not at all to 10=completely as instructed) rated at 6 and 12 months.

**Therapeutic Alliance Measures**

Therapeutic alliance was measured using the Working Alliance Inventory-Short Form (WAI) [27,35], a commonly used valid and reliable measure of the alliance [27], which contains 12 statements relating to perceived trust and agreement between the therapist and the client (eg, “My patient/physical therapist and I agree about the things they/I will need to do in therapy to help improve my situation”). Statements were rated using a 7-point scale ranging from never feeling (or thinking) that way, to always feeling (or thinking) that way. The WAI has 3 subscales: (1) task (agreement on management methods being used; items 1, 2, 8, and 12); (2) bond (feelings of appreciation and trust; items 3, 5, 7, and 9), and (3) goal (agreement on aims and objectives of treatment; items 4, 6, 10, and 11), which are summed together to give a total score ranging from 12 to 84 (higher scores indicate a stronger alliance) [27,35].

As recommended [27], both patients and physical therapists completed the WAI separately, after their second consultation (approximately week 4 of the intervention). Although therapeutic alliance was also measured in the RCT at the end of the 6-month intervention, there was no significant change in total scores over time [28]. Thus, only scores obtained after the second consultation were used in this exploratory study.
Data Analysis

Means and SDs of the patient and physical therapist characteristics and therapeutic alliance ratings were calculated. Separate regression models were used to investigate whether the therapeutic alliance was associated with each outcome. For each continuous outcome, linear regression models for the 6 and 12-month outcomes (change from baseline) were fit, with random effects for each patient to account for the two measurements. The baseline outcome measurement, where available, was included in the model, as were terms for patient (sex, age, self-efficacy at baseline, treatment expectations) and physical therapist characteristics (years of experience, previous experience delivering care remotely) that could potentially influence both the therapeutic alliance measure and outcomes at 6 and 12 months. The effect of therapeutic alliance on outcomes at 6 and 12 months was estimated by including terms for the outcome measurement time point, therapeutic alliance score, and an interaction between the two. Global change scores were dichotomized and analyzed using mixed-effects logistic regression models. Separate models were fit for the patient and physical therapist ratings of the alliance. As data for physical therapist ratings of adherence were only collected at 6 months, a standard linear regression model was fit. Analysis was performed using Stata (StataCorp, version 15.1).

Results

Characteristics of Patients With Knee OA

Most of the 87 patients (Table 1) were female (55/87, 63%) and lived in the metropolitan areas of Australia (48/87, 55%). The mean age of the patients was 62.4 years (SD 9.1), and at baseline, their mean knee pain was 6.0 (SD 1.5) on an 11-point numeric rating scale. Patients had a mean of 6.3 (SD 1.8) telephonic consultations during the trial and rated their therapeutic alliance a mean of 75.3 (SD 7.4) out of a maximum of 84.
Table 1. Characteristics of people with knee osteoarthritis (n=87).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female sex, n (%)</td>
<td>55 (63)</td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
<td>62.4 (9.1)</td>
</tr>
<tr>
<td>BMI (kg/m^2), mean (SD)</td>
<td>31.1 (6.8)</td>
</tr>
<tr>
<td>Location</td>
<td></td>
</tr>
<tr>
<td>Metropolitan</td>
<td>48 (55)</td>
</tr>
<tr>
<td>Nonmetropolitan</td>
<td>39 (45)</td>
</tr>
<tr>
<td>Employment status, n (%)</td>
<td></td>
</tr>
<tr>
<td>Working full- or part-time</td>
<td>37 (43)</td>
</tr>
<tr>
<td>Unemployed or retired</td>
<td>50 (57)</td>
</tr>
<tr>
<td>Education, n (%)</td>
<td></td>
</tr>
<tr>
<td>Less than 3 years of high school</td>
<td>5 (6)</td>
</tr>
<tr>
<td>3 years or more of high school</td>
<td>19 (23)</td>
</tr>
<tr>
<td>Some tertiary training</td>
<td>21 (24)</td>
</tr>
<tr>
<td>Graduated from university or polytechnic</td>
<td>24 (29)</td>
</tr>
<tr>
<td>Any postgraduate study</td>
<td>15 (18)</td>
</tr>
<tr>
<td>Number of calls with physical therapist, mean (SD)</td>
<td>6.3 (1.8)</td>
</tr>
<tr>
<td>Therapeutic alliance (WAI(^b)) at week 4, mean (SD)</td>
<td>75.3 (7.4)</td>
</tr>
<tr>
<td>Knee pain (NRS(^c)) at baseline, mean (SD)</td>
<td>6.0 (1.5)</td>
</tr>
<tr>
<td>Physical function (WOMAC(^d)) at baseline, mean (SD)</td>
<td>29.3 (10.1)</td>
</tr>
<tr>
<td>Self-efficacy (ASES(^e)) at baseline, mean (SD)</td>
<td>20.2 (4.0)</td>
</tr>
<tr>
<td>Quality of life (AQoL(^f)) at baseline, mean (SD)</td>
<td>0.7 (0.2)</td>
</tr>
<tr>
<td>Fear of movement (BFMS(^g)) at baseline, mean (SD)</td>
<td>12.9 (3.5)</td>
</tr>
<tr>
<td>Treatment expectations, n (%)</td>
<td></td>
</tr>
<tr>
<td>No effect</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Minimal improvement</td>
<td>8 (9)</td>
</tr>
<tr>
<td>Moderate improvement</td>
<td>46 (53)</td>
</tr>
<tr>
<td>Large improvement</td>
<td>32 (37)</td>
</tr>
<tr>
<td>Complete recovery</td>
<td>1 (1)</td>
</tr>
</tbody>
</table>

\(^a\)Defined according to the Australian Statistical Geography Standard Remoteness Structure [36].

\(^b\)WAI: Working Alliance Inventory; scores range from 12 to 84, where higher scores indicate a stronger alliance.

\(^c\)NRS: numeric rating scale; ranges from 0 to 10, where lower scores indicate less pain.

\(^d\)WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; ranges from 0 to 68, where lower scores indicate better function.

\(^e\)ASES: Arthritis Self-Efficacy Scale: scores range from 3 to 30, where higher scores indicate greater self-efficacy.

\(^f\)AQoL: Assessment of quality of life instrument, ranges from −0.04 to 1.0, where higher scores indicate better quality of life.

\(^g\)BFMS: Brief Fear of Movement Scale; ranges from 0 to 24, where higher scores indicate lower fear of movement.

**Characteristics of Physical Therapists**

Half of the 8 physical therapists (Table 2) were male and 63% (5/8) worked exclusively in private physical therapy settings. Collectively, physical therapists had a mean of 13.8 (SD 8.2) years of clinical experience, and none had experience delivering care via telephone, although 25% (2/8) had experience doing so via Skype. Physical therapists consulted with a mean of 10.5 (SD 2.1) trial patients each, and rated the therapeutic alliance as a mean of 71.0 (SD 5.5) out of a maximum of 84.
Table 2. Characteristics of physical therapists (n=8).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female, n (%)</td>
<td>50 (50)</td>
</tr>
<tr>
<td>Age (years), mean (SD)</td>
<td>35.4 (8.2)</td>
</tr>
<tr>
<td>Clinical experience (years), mean (SD)</td>
<td>13.8 (8.2)</td>
</tr>
<tr>
<td>Number of patients consulted with in the trial, mean (SD)</td>
<td>10.5 (2.1)</td>
</tr>
<tr>
<td><strong>Work setting, n (%)</strong></td>
<td></td>
</tr>
<tr>
<td>Both private and public</td>
<td>2 (25)</td>
</tr>
<tr>
<td>Private</td>
<td>5 (63)</td>
</tr>
<tr>
<td>Public</td>
<td>1 (12)</td>
</tr>
<tr>
<td><strong>Previous experience delivering care remotely, n (%)</strong></td>
<td>6 (75)</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Yes (via Skype)</td>
<td>2 (25)</td>
</tr>
<tr>
<td>Yes (via telephone)</td>
<td>0 (0)</td>
</tr>
<tr>
<td><strong>Postgraduate training in knee osteoarthritis, n (%)</strong></td>
<td>3 (37)</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>5 (63)</td>
</tr>
<tr>
<td><strong>Postgraduate training in exercise, n (%)</strong></td>
<td>7 (88)</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>1 (12)</td>
</tr>
<tr>
<td><strong>Postgraduate training in behavior change\textsuperscript{a}, n (%)</strong></td>
<td>3 (37)</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>5 (63)</td>
</tr>
<tr>
<td>Therapeutic alliance (WAI\textsuperscript{b}) at week 4, mean (SD)</td>
<td>71.0 (5.5)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Excluding trial-specific training in person-centered principles and behavior change techniques.

\textsuperscript{b}WAI: Working Alliance Inventory; scores range from 12 to 84, where higher scores indicate a stronger alliance.

**Association of Patient-Rated Therapeutic Alliance With Outcomes**

Associations between patient ratings of therapeutic alliance and continuous and binary outcomes at 6 and 12 months are displayed in Tables 3 and 4, respectively. Data suggest that patient-rated therapeutic alliance was associated with some outcomes at 6 months. Regression coefficients show that a one-unit increase in the therapeutic alliance score was associated with (1) a $-0.10$ (95% CI $-0.16$ to $-0.03$) unit improvement in overall average knee pain measured via a numeric rating scale; (2) a $-0.13$ (95% CI $-0.23$ to $-0.04$) unit worsening in fear of movement; (3) a $0.16$ (95% CI $0.04$ to $0.28$) unit improvement in self-efficacy; (4) increased odds of global improvement in physical function (odds ratio [OR] 1.21, 95% CI 1.04-1.39), and (5) increased odds of a global improvement overall (OR 1.26, 95% CI 1.06 to 1.51).

Data suggest that patient-rated therapeutic alliance was associated with some outcomes at 12 months. A one-unit increase in the therapeutic alliance score was associated with (1) a 0.15 (95% CI 0.03 to 0.27) unit improvement in self-efficacy; (2) increased odds of a global improvement in pain (OR 1.14, 95% CI 1.01 to 1.30); (3) increased odds of a global improvement in physical function (OR 1.19, 95% CI 0.03 to 1.37), and (4) increased odds of a global improvement overall (OR 1.21, 95% CI 1.02 to 1.42).
Table 3. Associations between patient and physical therapist ratings of the therapeutic alliance and changes in continuous outcomes at 6 and 12 months.\(^a\)

<table>
<thead>
<tr>
<th>Outcome</th>
<th>6 months</th>
<th>12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient rating of therapeutic alliance</strong></td>
<td><strong>Regression coefficient(^b) (95% CI)</strong></td>
<td><strong>P value</strong></td>
</tr>
<tr>
<td>Overall average knee pain (NRS(^c))</td>
<td>(-0.10 (-0.16 to 0.03))</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Physical function (WOMAC(^d) C)</td>
<td>(-0.10 (-0.40 to 0.20))</td>
<td>.52</td>
</tr>
<tr>
<td>Fear of movement (BFMS(^e))</td>
<td>(-0.13 (-0.23 to 0.04))</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Health-related quality of life (AQoL(^f))</td>
<td>(0.01 (0.01 to -0.01))</td>
<td>.43</td>
</tr>
<tr>
<td>Self-efficacy (total; ASES(^g))</td>
<td>(0.16 (0.04 to 0.28))</td>
<td>.01</td>
</tr>
<tr>
<td>Overall self-rated adherence to prescribed exercise</td>
<td>(0.09 (-0.02 to 0.20))</td>
<td>.11</td>
</tr>
<tr>
<td>Self-rated adherence to prescribed physical activity</td>
<td>(0.08 (-0.02 to 0.18))</td>
<td>.10</td>
</tr>
<tr>
<td>Physical therapist-rated patient adherence</td>
<td>(0.02 (-0.04 to 0.09))</td>
<td>.49</td>
</tr>
</tbody>
</table>

| **Physical therapist rating of therapeutic alliance**                    | **Regression coefficient\(^b\) (95% CI)** | **P value** | **Regression coefficient\(^b\) (95% CI)** | **P value** |
| Overall average knee pain (NRS)                                         | \(-0.02 (-0.11 to 0.06)\)                                                 | .55           | \(-0.06 (-0.14 to 0.02)\)                | .15          |
| Physical function (WOMAC C)                                             | \(-0.14 (-0.50 to 0.23)\)                                                 | .47           | \(-0.03 (-0.40 to 0.35)\)                | .89          |
| Fear of movement (BFMS)                                                 | \(-0.07 (-0.20 to 0.06)\)                                                 | .28           | \(-0.08 (-0.21 to 0.04)\)                | .20          |
| Health-related quality of life (AQoL)                                   | \(0.01 (-0.01 to 0.01)\)                                                 | .25           | \(0.01 (0.0003 to 0.01)\)                | .04          |
| Self-efficacy (total; ASES)                                             | \(0.06 (-0.11 to 0.23)\)                                                 | .50           | \(0.04 (-0.13 to 0.22)\)                 | .65          |
| Overall self-rated adherence to prescribed exercise                      | \(0.03 (-0.11 to 0.18)\)                                                 | .65           | \(-0.03 (-0.17 to 0.11)\)                | .67          |
| Self-rated adherence to prescribed physical activity                     | \(0.03 (-0.10 to 0.16)\)                                                 | .67           | \(-0.01 (-0.14 to 0.12)\)                | .90          |
| Physical therapist-rated patient adherence                               | \(0.05 (-0.03 to 0.13)\)                                                 | .24           | ---                                       | ---          |

\(^a\)Calculated as follow-up (6 or 12 months) minus baseline.

\(^b\)Regression coefficients are not standardized. Regression models were adjusted and baseline outcome measures, patient variables (gender, age, self-efficacy at baseline, treatment expectations), and physical therapist variables (years of experience, previous experience delivering care remotely) were included as covariates.

\(^c\)NRS: numeric rating scale; ranges from 0 to 10. Negative coefficients indicate that a stronger therapeutic alliance is associated with reduced pain over time.

\(^d\)WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; ranges from 0 to 68. Negative coefficients indicate that a stronger therapeutic alliance is associated with reduced functional impairment over time.

\(^e\)BFMS: Brief Fear of Movement Scale; ranges from 0 to 24. Positive coefficients indicate that a stronger therapeutic alliance is associated with an improvement in fear of movement over time.

\(^f\)AQoL: Assessment of quality of life instrument, ranges from -0.04 to 1.0. Positive coefficients indicate that a stronger therapeutic alliance is associated with improvement in quality of life over time.

\(^g\)ASES: Arthritis Self-Efficacy Scale: scores range from 3 to 30. Positive coefficients indicate that a stronger therapeutic alliance is associated with improvement in self-efficacy over time.

\(^h\)—: Outcome measure not collected at 12 months.
Among those with musculoskeletal conditions have found that existing reviews focusing on traditional, in-person consultations for telephone-delivered physical therapy care in adults with OA. This is the first study to investigate the relationship between therapeutic alliance and clinical outcomes following telephonic consultations was associated with outcomes at 6 and 12 months, including better adherence to physical-therapist–prescribed exercise and physical activity [37], improved global effects (pain, physical function, disability) [21], and greater treatment satisfaction [37,38]. We also found some evidence of an association with improved global effects; however, our data did not indicate a strong association between therapeutic alliance and exercise adherence or treatment satisfaction. The reason remains unclear. However, we measured adherence and satisfaction using self-reported questionnaires and analyzed associations with a valid and reliable measure of therapeutic alliance. Other studies included in a review by Babatunde et al, [37] have qualitatively explored the relationship between therapeutic alliance and adherence, or used unvalidated custom-developed measures of alliance, which makes comparisons with our findings difficult. In addition, we found that a higher therapeutic alliance was associated with greater improvements in self-efficacy over time. To our knowledge, no previous studies have examined the association between therapeutic alliance and changes in self-efficacy. Intuitively, this finding makes sense, in that greater perceived agreement on tasks and goals and a greater perceived bond with therapists is related to improvements in confidence and belief in one’s ability. Unexpectedly, we found that a higher patient-perceived therapeutic alliance was associated with worsening of fear of movement at 6 months, but at 12 months, the direction of the association was uncertain. In the overarching clinical trial, fear of movement worsened over time in both the intervention and control groups, with no differences in change between groups [10]. To our knowledge, no other studies have examined the association between therapeutic alliance and change in fear of movement after treatment; thus, further research is required to confirm this finding. 

### Discussion

#### Principal Findings

The aim of this study was to investigate whether the therapeutic alliance between patients and physical therapists during telephonic consultations was associated with outcomes following exercise and advice for people with knee OA. The findings suggest that patient-rated therapeutic alliance was weakly associated with some outcomes at 6 and 12 months, including improvements in pain, self-efficacy, global function, and overall global improvement, in addition to a worsening in fear of movement. The data indicated that associations between physical therapist-rated therapeutic alliance and outcomes were not meaningful. The observed relationships were generally weak and thus unlikely to be clinically significant.

#### Comparison With Earlier Work

This is the first study to investigate the relationship between therapeutic alliance and clinical outcomes following telephone-delivered physical therapy care in adults with OA. Existing reviews focusing on traditional, in-person consultations among those with musculoskeletal conditions have found that a stronger therapeutic alliance between the patient and their physical therapist is associated with improved outcomes, including better adherence to physical-therapist–prescribed exercise and physical activity [37], improved global effects (pain, physical function, disability) [21], and greater treatment satisfaction [37,38]. We also found some evidence of an association with improved global effects; however, our data did not indicate a strong association between therapeutic alliance and exercise adherence or treatment satisfaction. The reason remains unclear. However, we measured adherence and satisfaction using self-reported questionnaires and analyzed associations with a valid and reliable measure of therapeutic alliance. Other studies included in a review by Babatunde et al, [37] have qualitatively explored the relationship between therapeutic alliance and adherence, or used unvalidated custom-developed measures of alliance, which makes comparisons with our findings difficult. In addition, we found that a higher therapeutic alliance was associated with greater improvements in self-efficacy over time. To our knowledge, no previous studies have examined the association between therapeutic alliance and changes in self-efficacy. Intuitively, this finding makes sense, in that greater perceived agreement on tasks and goals and a greater perceived bond with therapists is related to improvements in confidence and belief in one’s ability. Unexpectedly, we found that a higher patient-perceived therapeutic alliance was associated with worsening of fear of movement at 6 months, but at 12 months, the direction of the association was uncertain. In the overarching clinical trial, fear of movement worsened over time in both the intervention and control groups, with no differences in change between groups [10]. To our knowledge, no other studies have examined the association between therapeutic alliance and change in fear of movement after treatment; thus, further research is required to confirm this finding.

### Table 4. Associations between patient and physical therapist ratings of the therapeutic alliance and binary outcomes at 6 and 12 months.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>6 months OR (95% CI)</th>
<th>P value</th>
<th>12 months OR (95% CI)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient rating of therapeutic alliance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved pain</td>
<td>1.12 (0.99 to 1.26)</td>
<td>.08</td>
<td>1.14 (1.01 to 1.30)</td>
<td>.03</td>
</tr>
<tr>
<td>Improved physical function</td>
<td>1.21 (1.04 to 1.39)</td>
<td>.01</td>
<td>1.19 (1.03 to 1.37)</td>
<td>.02</td>
</tr>
<tr>
<td>Improved overall</td>
<td>1.26 (1.06 to 1.51)</td>
<td>.01</td>
<td>1.21 (1.02 to 1.42)</td>
<td>.03</td>
</tr>
<tr>
<td>Satisfied with care received</td>
<td>1.12 (0.95 to 1.33)</td>
<td>.17</td>
<td>1.10 (0.96 to 1.25)</td>
<td>.18</td>
</tr>
<tr>
<td>Increased physical activity levels</td>
<td>1.09 (0.96 to 1.24)</td>
<td>.18</td>
<td>1.11 (0.97 to 1.26)</td>
<td>.12</td>
</tr>
<tr>
<td><strong>Physical therapist rating of therapeutic alliance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved pain</td>
<td>1.07 (0.93 to 1.24)</td>
<td>.33</td>
<td>1.10 (0.95 to 1.28)</td>
<td>.21</td>
</tr>
<tr>
<td>Improved physical function</td>
<td>1.13 (0.95 to 1.33)</td>
<td>.17</td>
<td>1.04 (0.89 to 1.22)</td>
<td>.63</td>
</tr>
<tr>
<td>Improved overall</td>
<td>1.13 (0.94 to 1.36)</td>
<td>.18</td>
<td>1.09 (0.92 to 1.31)</td>
<td>.32</td>
</tr>
<tr>
<td>Satisfied with care received</td>
<td>1.16 (0.94 to 1.43)</td>
<td>.16</td>
<td>0.89 (0.73 to 1.09)</td>
<td>.26</td>
</tr>
<tr>
<td>Increased physical activity levels</td>
<td>1.04 (0.90 to 1.20)</td>
<td>.57</td>
<td>1.06 (0.92 to 1.23)</td>
<td>.39</td>
</tr>
</tbody>
</table>

aRegression models were adjusted and baseline outcome measures, patient variables (gender, age, self-efficacy at baseline, and treatment expectations), and physical therapist variables (years of experience and previous experience delivering care remotely) were included as covariates.  
bOR: odds ratio; ORs >1 indicate greater odds of reporting improvement in outcome or satisfaction with care with a stronger therapeutic alliance.
Our findings are broadly similar to those of previous research exploring therapeutic alliance in tele-rehabilitation consultations with clinicians outside of the physical therapy profession. One study of 22 adolescents (mean age 15 years) with idiopathic arthritis who received care via 12 telephonic consultations from trained nonprofessional health coaches over 12 weeks found that therapeutic alliance was correlated with improved treatment outcomes, including decreased pain [39]. However, the authors only reported correlation coefficients, which makes comparisons with the magnitude of association observed in our study difficult. Other populations of people with psychological disorders (eg, post-traumatic stress disorder, anxiety, depression, cancer stress) have found that therapeutic alliances during therapist-led remotely delivered (ie, via video or telephone) cognitive behavioral therapy is associated with improvements in outcomes (eg, reduced symptoms of depression and anxiety, increased compliance) at 5 to 18 weeks [40-42]. However, given paucity of evidence, particularly in remotely delivered physical therapy, further research is required.

Although we observed associations between therapeutic alliance and outcomes, the coefficients were very small and confidence intervals contained values that were close to zero. Thus, the clinical significance of our observed relationships is unclear. A single unit increase in therapeutic alliance score (measured on a scale of 12 to 84, with an SD of 7.4) corresponded to a very small, 0.10-unit improvement in overall average knee pain (measured on an 11-point numeric rating scale) at 6 months. This magnitude of change is similar to that observed by Ferreira et al [43], who investigated associations between therapeutic alliance and clinical outcomes following 12 in-person consultations with physical therapists over 8 weeks for patients with low back pain. This suggests that consulting via telephone does not change the relationship between therapeutic alliance and outcomes when compared with being in-person. Ferreira et al [43] found that a 1-SD increase in therapeutic alliance score (measured using a different version of the WAI to the one used in our study) corresponded to a 0.6-unit improvement in pain (measured on an 11-point numeric rating scale). For context, the minimal clinically important difference for pain following interventions for people with OA is an absolute change of 2.0 units on a numeric rating scale [44], which suggests that therapeutic alliance may not have a clinically significant impact on pain. In quality of life, a 1-SD increase in physical therapist-rated therapeutic alliance score in our study corresponds to a 0.055-unit improvement in quality of life, approximating the estimated minimal clinically important difference of 0.06 on the AQoL [45]. Minimal clinically important differences for other outcome measures that we found were associated with therapeutic alliance (including self-efficacy and fear of movement) are unknown [46], and as such, the clinical significance of associations with these outcomes is unclear.

Our patient and physical therapist ratings of the therapeutic alliance were high [28], and the small SD suggests that there was no significant variability in scores. This does not appear to be unique to our sample, as other studies investigating therapeutic alliances in physical therapy or tele-rehabilitation have also observed high scores with low variability in their sample [39,43]. A variety of tools have been used to evaluate therapeutic alliance [37]; however, none have been validated for use in musculoskeletal physical therapy settings. These existing tools may not necessarily capture domains of care that are important in physical therapy contexts [47] and have been found to demonstrate a ceiling effect [48]. Therefore, the development of measures that are validated in musculoskeletal physical therapy settings is important.

Our study is relevant to clinicians and researchers. The findings suggest that the strength of the therapeutic alliance with the physical therapist as perceived by the patient is associated with some clinical outcomes after telephonic consultations focused on exercise management. Thus, physical therapists should be mindful about the therapeutic alliance they build with their patients. To enhance the therapeutic alliance, it has been recommended that clinicians focus on fostering person-centered interactions with patients, including offering emotional support and facilitating patient involvement in decision-making [49-51]. It is also important to acknowledge, however, that we currently do not understand the clinical importance of the observed associations between therapeutic alliance and outcomes, and it is also not clear which strategies are best to increase therapeutic alliance. Further research is required to determine what specific components of care or clinician skills may need to be modified to enhance therapeutic alliance, and whether it is practical for physical therapists or other clinicians to adapt such skills in clinical practice. In addition, further research is required to investigate whether clinician experience with or training in remotely delivered care influences therapeutic alliance during telephonic consultations. Studies that include manipulation of therapeutic alliance may provide more insight into its importance in clinical practice. For example, Fuentes et al [52] randomized 117 people with chronic low back pain to enhanced and limited therapeutic alliance groups, where physical therapists either did not engage in conversation with patients and left the room during interferential current therapy (limited alliance group) or engaged in active listening and used empathetic language and encouragement (enhanced alliance group). They found that those allocated to the enhanced therapeutic alliance groups reported significantly greater improvements in pressure pain threshold and pain than those in the limited alliance group immediately after the treatment session.

Future research should consider evaluating relationships between therapeutic alliance and clinical outcomes in real-world clinical practice, as both alliance and clinical outcomes may be more varied than observed within the context of a clinical trial. Importantly, we found that physical therapist ratings of therapeutic alliance were generally not related to clinical outcomes, suggesting that their own perceptions of the alliance may not be as important as those of the patient. Our study was the first to investigate the relationship between therapeutic alliance and clinical outcomes following telephone-delivered physical therapy care in adults with OA, and thus further research is required to compare therapeutic alliance during tele-rehabilitation and traditional in-person consultations, and how it moderates treatment outcomes.
Limitations

Our study has some limitations. As with any study, there is a risk of type 1 error. However, in accordance with recommendations from the American Statistical Association [53], we did not interpret our results on the basis of statistical significance alone, instead considering the clinical significance of the findings. Before commencement of the trial, all trial physical therapists underwent training in person-centered care and behavior change techniques [30]. Our findings may not be generalizable to other physical therapists in the community who have not undergone such training. Most (5/8, 63%) of our physical therapists worked in private health care settings, where patients typically incur out-of-pocket costs for services. This broadly reflects the physical therapy workforce in Australia, where more than 60% of therapists work in private settings [54]. Thus, our findings may not be generalizable to other countries where physical therapists may work in alternate health care settings. We used the WAI to measure the therapeutic alliance between patients and physical therapists; however, this tool has not been validated for use in musculoskeletal physical therapy practice, and similar measures of therapeutic alliance have been found to demonstrate a ceiling effect [48]. Finally, a limitation of our study is that our dependent variables (clinical outcomes) were measured via participant-reported outcome measures. It is unclear if our findings may have differed had we used objectively measured outcomes (such as performance tests of physical function) which is an area where future research may be warranted.

Conclusions

In conclusion, higher patient ratings but not higher physical therapist ratings of the therapeutic alliance were weakly associated with improvements in some clinical outcomes. Although these findings suggest that patients who perceive a stronger alliance with their physical therapist may achieve some better clinical outcomes, the observed relationships were generally weak and unlikely to be clinically significant. Limitations include the fact that measures of therapeutic alliance have not been validated for use in musculoskeletal physical therapy settings. There was a risk of type 1 error; however, findings were interpreted based on clinical significance rather than statistical significance alone.

Acknowledgments

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Authors’ Contributions

The authors declare the following contributions to the preparation of the manuscript: study conception and design (BL, KB, and RH), inclusion and data collection (PC), data analysis (JK), and interpretation of data (all authors); drafting of the manuscript (BL); critical revision of the manuscript (all authors). All authors approved the final version of the manuscript.

Conflicts of Interest

None declared.

References


Abbreviations

AQoL: assessment of quality of life
NHMRC: National Health and Medical Research Council
OA: osteoarthritis
OR: odds ratio
RCT: randomized controlled trial
WAI: Working Alliance Inventory

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Electromyography-Driven Exergaming in Wheelchairs on a Mobile Platform: Bench and Pilot Testing of the WOW-Mobile Fitness System

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Abstract

Background: Implementing exercises in the form of video games, otherwise known as exergaming, has gained recent attention as a way to combat health issues resulting from sedentary lifestyles. However, these exergaming apps have not been developed for exercises that can be performed in wheelchairs, and they tend to rely on whole-body movements.

Objective: This study aims to develop a mobile phone app that implements electromyography (EMG)-driven exergaming, to test the feasibility of using this app to enable people in wheelchairs to perform exergames independently and flexibly in their own home, and to assess the perceived usefulness and usability of this mobile health system.

Methods: We developed an Android mobile phone app (Workout on Wheels, WOW-Mobile) that senses upper limb muscle activity (EMG) from wireless body-worn sensors to drive 3 different video games that implement upper limb exercises designed for people in wheelchairs. Cloud server recordings of EMG enabled long-term monitoring and feedback as well as multiplayer gaming. Bench testing of data transmission and power consumption were tested. Pilot testing was conducted on 4 individuals with spinal cord injury. Each had a WOW-Mobile system at home for 8 weeks. We measured the minutes for which the app was used and the exergames were played, and we integrated EMG as a measure of energy expended. We also conducted a perceived usefulness and usability questionnaire.

Results: Bench test results revealed that the app meets performance specifications to enable real-time gaming, cloud storage of data, and live cloud server transmission for multiplayer gaming. The EMG sampling rate of 64 samples per second, in combination with zero-loss data communication with the cloud server within a 10-m range, provided seamless control over the app exergames and allowed for offline data analysis. Each participant successfully used the WOW-Mobile system at home for 8 weeks, using the app for an average of 146 (range 89-267) minutes per week with the system, actively exergaming for an average of 53% of that time (39%-59%). Energy expenditure, as measured by integrated EMG, was found to be directly proportional to the time spent on the app (Pearson correlation coefficient, r=0.57-0.86, depending on the game). Of the 4 participants, 2 did not exercise regularly before the study; these 2 participants increased from reportedly exercising close to 0 minutes per week to exergaming 58 and 158 minutes on average using the WOW-Mobile fitness system. The perceived usefulness of WOW-Mobile in motivating participants to exercise averaged 4.5 on a 5-point Likert scale and averaged 5 for the 3 participants with thoracic level injuries. The mean overall ease of use score was 4.25 out of 5.
Conclusions: Mobile app exergames driven by EMG have promising potential for encouraging and facilitating fitness for individuals in wheelchairs who have maintained arm and hand mobility.

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KEYWORDS

exergaming; gamercising; mobile health; wheelchair exercises; wireless electromyography; mobile phone

Introduction

Individuals with paraplegia are at a greater risk for many secondary health problems associated with sedentary behavior [1-3]. The benefits of physical exercise on the health and quality of life of people with disabilities have been reported [4-6]. Dishearteningly, individuals with impaired mobility face substantial barriers to exercise, such as difficulty in accessing exercise programs and facilities, which contribute to an overall reduction in participation in physical activity [7-9]. With the known benefits that physical exercise has on health, digital sensor-driven technology is being considered as an approach to make exercise more accessible and entertaining [10-14]. Exercising in the process of achieving the objectives of a digital video game is termed exergaming [15,16]. Reportedly, 61% of internet-based exercise interventions lead to significant gains in physical activity [17]. Some researchers have gamified exercises to encourage more active lifestyles [16,18,19]. A recent review paper examined studies showing the beneficial health effect of exergaming and pointed to the ripe opportunity to apply exergaming to the health issues that individuals with neurological disabilities face [14]. At its inception, exergaming was popularized as arcade games or console games and has more recently been implemented as desktop and web apps [20-25]. Now, exergaming is beginning to appear on mobile platforms (namely, smartphones and tablets) [16,26,27], which could help in overcoming transportation challenges and inaccessible gym environments for people using wheelchairs. However, among those that have been implemented, there are none to the authors’ knowledge that are tailored to exergaming in wheelchairs.

We have developed a mobile app that communicates with body-worn sensors that monitor physical activity and feed electromyography (EMG) input into a mobile app game engine that gamifies exercises designed to be carried out independently by individuals in wheelchairs. The current recommendations for exercise regimens for individuals in wheelchairs holistically combine cardiovascular conditioning and strength training [28]. Evidence of the need for building muscle strength to prevent overuse injury and pain and to enable individuals in wheelchairs to sustain sufficient exercise on a weekly routine basis has led to the development of exercise interventions, such as circuit resistance training (CRT), which include muscle strengthening [28,29]. CRT entails interspersing arm resistance strength exercises (such as weight lifting) with high-speed cardiovascular exercise (such as arm cranking) and incomplete recovery periods during which the heart rate was still sustained well above the resting heart rate. Our app implements these exercises in the form of 3 different games that allow the user to engage in a combination of resistance and aerobic conditioning activities developed to be used in a wheelchair.

Many of the existing fitness apps rely on heart rate and accelerometers. The well-known exergames (eg, Dance Dance Revolution and balance board–centered Wii Fit) rely on step detection or lower limb mobility for an effective workout [12,21-23,30,31]. These systems use pressure sensors to detect body weight or accelerometers to detect ballistic or discrete movements. Accelerometers have sufficient resolution to detect steps and therefore have been relatively effective in fitness apps to date when the physical activity being tracked involves moving the whole body mass. In contrast, detecting muscle activity provides a real-time measurement of continuous changes in physical exertion, that is, by sensing muscle activity via EMG, we would be able to detect the continuous intensity of each muscle contraction rather than only binary detection of a movement. This is especially important in the case of individuals with paraplegia, where the movements involve only the upper body and not their whole body and where strength training entails isometric contractions rather than binary actions (eg, steps, cycles). Commercial wireless EMG sensors are beginning to be used with mobile apps for applications such as monitoring driving and monitoring cadence while biking [32,33]. Our app senses EMG to measure the amount of muscle activity continuously used. Therefore, our app can sense the strength of isometric contractions during muscle strengthening exercises as well as how hard a wheelchair push was during spinning exercises.

The limitation of the existing technology to facilitate and encourage exercise for individuals with lower limb mobility impairment is the lack of a combination of providing exergaming on a mobile platform and tailoring games toward exercises that can be performed in wheelchairs; of particular need for such exergames is the ability to track isometric contractions through EMG sensing. Our objective was to design, implement, and test the feasibility of an EMG-based mobile exergaming app for individuals in wheelchairs. Our mobile app is distinct from other fitness apps in a few key ways. First, the app gamifies exercises that can be performed in a wheelchair on a mobile platform while monitoring effort and providing feedback, thereby making exercises entertaining and accessible. Second, the selection of the exercises was informed by research on the fitness needs of individuals who use wheelchairs as a primary mode of transportation. In particular, the exercises were specifically selected so that individuals in wheelchairs could exercise independently without relying on access to adapted equipment or specialists or physical therapists for their daily physical exercise. Third, the games were driven by EMG, which enables higher resolution and continuous readings of physical exertion from upper limb movements.
The purpose of this study, therefore, is to describe the development and feasibility of a mobile phone app that implements EMG-driven exergaming to encourage and enhance exercise for individuals who use wheelchairs. In this work, we assess the perceived usefulness and usability of this mobile health system by asking the following research questions:

1. Does this mobile fitness app enable individuals who use wheelchairs to increase their level of physical activity?
2. Does use of this mobile fitness app allow individuals who use wheelchairs to reach their self-reported peak fitness levels?
3. Does this mobile fitness app improve self-reported motivation to exercise?
4. Does this mobile fitness app enhance the effectiveness of a workout session for individuals who use wheelchairs?
5. Does this mobile fitness app allow the user to track their progress?
6. How do users perceive the ease of use of this app?

These questions pertain not to a generic mobile fitness app but to one specifically designed to enable people in wheelchairs to perform exergames, used in CRT, independently and flexibly in their own home. As such, the Methods section describes the implementation of our Workout on Wheels (WOW) mobile fitness app.

**Methods**

**Mobile Fitness App Concepts**

We designed a mobile fitness app, called Workout on Wheels—Mobile (or WOW-Mobile), to encourage and facilitate exercises at home for individuals who have lower mobility impairment and use wheelchairs for ambulation. Table 1 provides an overview of the features or enabling technology that we incorporated into our app design to achieve specific objectives. Ultimately, the goal of the overall design of the app is to help app users achieve greater fitness levels than without the app.

The hardware system and architecture are described elsewhere [34]. Here, we describe the implementation of our design and show the feasibility of achieving these design objectives through the integration of EMG sensing with our mobile fitness app. All code was written in Java using the Android Studio IDE, and the mobile app was installed and tested on the Samsung Galaxy J3.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Enabling design or technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal-oriented exercise</td>
<td>Exergaming</td>
</tr>
<tr>
<td>Holistic exercise workout in wheelchairs</td>
<td>Spinning, boxing, and arm resistance games</td>
</tr>
<tr>
<td>Increase in fitness levels</td>
<td>Electromyography-driven game engines (game performance correlates with effort level)</td>
</tr>
<tr>
<td>Fitness tracking</td>
<td>Calories metric, trends page</td>
</tr>
<tr>
<td>Encouragement</td>
<td>Audio feedback, text pop-ups</td>
</tr>
<tr>
<td>Independence, flexibility</td>
<td>Wireless sensing, mobile platform</td>
</tr>
<tr>
<td>Competition</td>
<td>Multiplayer gaming</td>
</tr>
<tr>
<td>Socialization</td>
<td>Leaderboard</td>
</tr>
</tbody>
</table>

Sensor Validation and App Bench Testing

Wireless EMG sensors (Flexdot, DynoFit Inc) were used to drive the exergames and provide feedback on estimated energy expenditure (Multimedia Appendix 1). In addition to the 3 exergames described in the following sections, users also had access to a monitoring activity, which simply displays the signals obtained from the wearable sensors. To validate the EMG acquisition and sensing, we collected surface EMG readings from the bicep brachii muscle from 2 brands of sensors: the Flexdot and the Trigno (Delsys, Inc), a popular high-end commercial wireless EMG sensor and data acquisition system. The mobile fitness system was tested in our research laboratory for power consumption and data transmission performance using Android Studio Profiler. The results from this testing are presented in a later section (WOW-Mobile Validation and Bench Testing).

**Exergame and Monitoring Concepts**

We created 3 video games within our mobile phone app (Multimedia Appendices 2-4) to implement corresponding exercises that were developed by coauthors from the School of Kinesiology as part of a circuit training regimen [35]. de Leon established a mobility center on our campus that provides individuals in our community with mobility impairment because of spinal cord injury (SCI) and other causes with very low-cost physical therapy. Other coauthors served as trainers in the clinic and led the development of the exercise protocol on which the exergames were based. The training circuit was designed to help people with SCI achieve recommended cardiorespiratory intensity levels and provide strengthening and endurance to help prevent repetitive use injuries [28,36]. A brief description of the gamified exercises is provided in Table 2. Each game provided an entertaining objective that users could focus on and help them exercise at appropriate intensity levels without focusing on the exercise themselves. It also provided feedback to the user to encourage gains in strength, endurance, and cardiorespiratory fitness in the form of game performance metrics. Audio-visual feedback was incorporated to encourage users to meet the game objectives.
### Table 2. Conceptual design of Workout on Wheels-Mobile exergames.

<table>
<thead>
<tr>
<th>Game</th>
<th>Analogous exercise</th>
<th>Exercise objective</th>
<th>Game objective</th>
<th>Feedback provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racing</td>
<td>Spinning</td>
<td>High cadence, low resistance</td>
<td>Complete designated number of laps within target time</td>
<td>Time to complete given number of laps. HR(^a), EMG(^b) level, and METs(^c). Audio of car engine; visual of car speed based on EMG level.</td>
</tr>
<tr>
<td>High striker</td>
<td>Resistance armbands</td>
<td>Isoinertial resistance (via shoulder press, chest fly, bicep curls)</td>
<td>Raise bar level to upper target with EMG</td>
<td>Number of flexions detected; number of hits of upper target. Audio (bell) when upper target reached. Visual of bar height based on the EMG level. Max EMG reached, HR, and METs.</td>
</tr>
<tr>
<td>Boxing</td>
<td>Ball exchange</td>
<td>Maintain HR with a high-cadence, low-resistance exercise + adds variety.</td>
<td>Complete 3 rounds of punches</td>
<td>Audio (punch sound) and visual (stars) with each detected punch.</td>
</tr>
</tbody>
</table>

\(^a\)HR: heart rate.  
\(^b\)EMG: electromyography.  
\(^c\)MET: metabolic equivalent.

### Calibration and Goals

Thresholds must be set before playing an exergame to appropriately calibrate each game performance with the user’s effort level. A calibration activity was developed, which guides the user through 3 maximum voluntary contractions (MVCs) of the selected muscle (tested separately for the bicep, tricep, anterior deltoid, and posterior deltoid). The average EMG level over a 3-second period during the MVC was used as the 100% effort level. We measured the MVC during orientation in a laboratory setting. EMG thresholds were required for the detection of each muscle contraction in the boxing and high striker game and to calibrate the car’s speed in the racing game. A MyGoals activity (Figure 1) was also created to allow the user to save their thresholds so that it does not need to be reentered for each session; rather, the thresholds are fetched for the appropriate game at the start of each session. MVC was measured at baseline testing using the Calibration activity. For the high striker game, the upper and lower thresholds were set to 90% and 20%, respectively, of the baseline MVC; for the boxing game, the upper and lower thresholds were set to 80% and 30%, respectively, of MVC. For the racing game, the upper threshold was set to 100% of the MVC, and the lower threshold was set to the empirically determined noise floor.
**High Striker: Arm Resistance Band Game Design and Implementation**

The high striker game replicated the game typically found at carnivals (Multimedia Appendix 2). The player hits one end of a lever to launch a puck up a graduated column. The greater the force the player uses, the higher the puck climbs up the height of the column. The player wins if the puck reaches the top of the column and strikes a bell. We implemented resistance arm band exercises as a game based on the high striker (Figure 2). The column is represented by a bar whose height is proportional to the integrated EMG level over a given contraction (Figure 3). The user selects which muscle’s EMG should drive the bar’s height according to the exercise they plan to perform and on which they are currently focusing (e.g., biceps for the bicep curls or anterior deltoids for the shoulder press and chest fly). As the user performs each contraction, the number of contractions (or hits) detected is incremented, and the number of times the maximum target (or bell) was hit is incremented. The user interface also includes encouraging text pop-ups, upbeat background music, and the bell audio clip each time the bar reaches the maximum.
Figure 2. User carrying out chest press exercise to play the high striker exergame.

Figure 3. Screenshots showing the app interface for the high striker arm resistance band exergame. User selects which muscle to monitor. The ratio of the yellow bar height to the scaled background bar is equal to the iEMG: MVC level. (a) Interface during the middle of the game. Feedback also includes encouraging text, number of reps, and number of bells hit. (b) Interface at the end of the game, providing summary statistics and a prize based on the number of bells. iEMG: integrated electromyography; MVC: maximum voluntary contraction.

**Boxing: Exchange Game Design and Implementation**

The workout developed for this research project included a second high cadence, low-resistance exercise to add variety to the cardiorespiratory exercise, maintain heart rate between the other exercises, and reduce the risk of overuse injury. This exercise was implemented as a boxing game (Figure 4, Multimedia Appendix 4). Players need to complete 30 punches to advance to the next round; there are 3 rounds (Figure 5). To progressively increase the workout intensity, the threshold that defined what constituted a punch increased with each round.
Figure 4. Participant plays the boxing exergame. The EMG sensor can be seen on the right bicep; phone is suspended by phone holder so that the user can monitor progress while playing. EMG: electromyography.

Figure 5. Sequence of screenshots during the boxing game. Each round gets progressively more difficult (the threshold for a punch being detected increases).
Car Racing: Cardio-Spinning Game Design and Implementation

The spinning exercise was implemented as a car racing game (Figure 6, Multimedia Appendix 3). The angle of the elliptical path around the track increased in proportion with the effort level, whereas the user spun on a stationary roller (Invictus Active Trainer). The effort level was computed as the ratio of the EMG amplitude to the MVC for the given muscle. The metrics displayed to the user during the game included the elapsed time, number of laps to complete, total calories burned, and the current METs. The sound of an engine running would play as background audio throughout the game, whereas an audio clip of One final lap! would play as the lap counter decreased to 1 to encourage the user.

We also implemented a multiplayer gaming feature that allows users to select a previous session to be played back as a ghost player against which to race. This feature is outside the scope of this paper and is described in a separate paper.

Figure 6. Single-player track game: Angular speed of the car is proportional to the EMG (level for a punch being detected increases). EMG: electromyography.

Pilot and Feasibility Testing

In total, 4 individuals with incomplete SCI took home and used our WOW-Mobile system for 8 weeks. The California State University, Los Angeles institutional review board approved all study procedures (#18–273). Participant demographics are listed in Table 3. Of 4 participants, 1 (25%) already had an adapted gym at their home and exercised regularly before participating in the study, another had access to adapted exercise equipment in the apartment building, and the other 2 did not have access to a gym and did not exercise regularly before participating in the study. None of the participants had prior experience with exergaming.
Before beginning the 8 weeks, each participant came to our campus for orientation to the mobile fitness system in a controlled laboratory setting. Physical trainers from the Kinesiology department gave instructions on how to carry out the exercises at home, and they, along with engineering research students who developed the app, guided the participants through a practice session of placing sensors, positioning the armbands, and carrying out the exergames on the mobile app. These physical trainers and engineering students then went to the participants’ homes to set up a stationary spinning device and provided a mobile phone with WOW-Mobile installed, sensors, electrodes, spare batteries, and resistance armbands (TheraBand) and guided the participant one more time through the mobile fitness workout. A workout frequency of 3 times a week for 45 minutes each was recommended to the participants. The messaging mobile app WhatsApp (Facebook, Inc) was installed on the participants’ phones; a chat room including the participants, engineers, and trainers was created. Participants were instructed to provide feedback regarding the WOW-Mobile app and were encouraged to message the group any time they had issues or questions regarding the app. The participants were visited once at 4 weeks to replenish supplies and check if there were any problems they faced using the app that could better be addressed in person. Participants were paid a weekly US $25 participation stipend for logging into the app at least twice a week, but participants were free to use the app as they chose. This was the same compensation provided for a separate study on gym-based exercise.

Data written to the cloud from each game session were analyzed for number of log-ins, time spent on the app, and actual time spent playing the games. In addition, by analyzing the acquired EMG signals, we also measured the number of detected muscle contractions, the integrated EMG levels (iEMG), and peak EMG levels during each game session using custom-written MATLAB code (Mathworks, Inc). A Likert-scale survey, based on a widely used questionnaire for the perceived usefulness, perceived usability, and user acceptance of information technology, was administered on the web after the 8-week training period.

Before any pilot testing on these 4 participants, 2 other participants were enrolled to conduct feasibility testing. Feasibility testing was conducted to ensure that individuals with moderate and very limited upper mobility would be able to set up and carry out the exergames on their own. These participants helped provide feedback on the app, and several features were modified and some functionality was corrected as a result of their input. Examples include changing the background in the racing game, making threshold adjustments more user-friendly with the calibration feature and saving the user’s default thresholds, and enlarging the control buttons on the screen to make navigating the app more user-friendly.

### Usability of the System

The usability of the system was addressed via a web survey administered through Qualtrics. Participants who had used the WOW-Mobile app were asked 21 questions regarding the usability and usefulness of the app. Of the 21 questions, 18 (86%) were ranked on a Likert scale and 3 were open ended. All 4 WOW-Mobile pilot participants responded to the survey. The mean and SDs were calculated using SPSS Statistics 24 for the quantitative questions, and the qualitative questions are described below. Given that the sample size was 4 and the qualitative responses were very brief, these responses were not analyzed using a qualitative coding method and are presented below.

### Results

#### WOW-Mobile Validation and Bench Testing

The performance specifications of the wireless sensors are provided in Table 4. The sampling rate is sufficiently fast to provide what appears to the user to be continuous monitoring of muscle activity, heart rate, and acceleration. All use Bluetooth Low Energy, which provides reliable wireless transmission of the physiological data while optimizing for energy consumption. They are all battery operated, and batteries can either be very easily replaced or have a rechargeable battery.
Table 4. Workout on Wheels-Mobile sensor performance specifications.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Electromyography sensor</th>
<th>Alpha 2 heart rate monitor (Mio Global)</th>
<th>Custom accelerometry module</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling rate</td>
<td>64 Hz</td>
<td>Continuously</td>
<td>4 Hz</td>
</tr>
<tr>
<td>ADC resolution</td>
<td>15 bits</td>
<td>Unknown (1 BPM)</td>
<td>10 bit</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>0-60 V</td>
<td>30-220 BPM</td>
<td>±8G</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3.5 cm×3.5 cm×1.2 cm</td>
<td>4.5 cm×3.2 cm×1.5 cm+wrist strap</td>
<td>3.8 cm×5 cm×1.27 cm+wrist strap</td>
</tr>
<tr>
<td>Wireless protocol</td>
<td>Bluetooth Low Energy</td>
<td>Bluetooth Low Energy</td>
<td>Bluetooth Low Energy</td>
</tr>
<tr>
<td>Battery</td>
<td>3 V 210 mAh Li coin cell</td>
<td>3.7 V 170 mAh Li-Po</td>
<td>Rechargeable 3.7 V 500 mAh Li-Po</td>
</tr>
<tr>
<td>Battery life</td>
<td>8 hours of transmission</td>
<td>5 years</td>
<td>5 years</td>
</tr>
</tbody>
</table>

aADC: analog to digital converter.
bBPM: beats per minute.

The raw EMG from the Trigno during 3 sets of 5 bicep curls is shown in blue in Figure 7. The Flexdot performs on-board signal processing and transmits a 2-pole low-pass filtered EMG envelope, shown in red in Figure 7. The Flexdot envelope can be seen to accurately track the gold standard activity acquired by Trigno. Some differences are expected because of the differences in the position of the sensors. The Flexdot and Trigno were placed adjacent to each other on the same muscle belly. The completely stand-alone wireless nature of the Flexdot and the Bluetooth transmission enable the user to use our app virtually anywhere at any time. Other commercial wireless EMG systems require a base station connected via a USB cable to a computer or otherwise require tethering to a computer.

Figure 7. EMG acquired by the Flexdot sensors (red) accurately captured the envelope of the raw EMG activity that was measured by high-end commercial EMG sensors (blue). EMG: electromyography.

All data collected from the connected sensors were written to the server at the end of each game session. Data transmission was monitored on Android Studio Profiler, whereas the user wearing the sensors walked gradually away from the phone. The range of transmission for the Bluetooth connection was 10 m inside the building and as far as 100 m in an unobstructed environment. Within the 10-m range, there was zero packet loss. Server upload and download speed were monitored on Speedtest by Ookla and was measured to be 54.8 Mbps and 55.3 Mbps, respectively. Data from a 10-second game with 1 Flexdot connected, for example, require 5 milliseconds on average to write.

Pilot Study Results

A total of 4 participants with varying levels of SCI, whose primary mode of ambulation is by wheelchair, exergamed on a weekly basis for 8 weeks using our WOW-Mobile app. The mean time spent on the app ranged from 89 to 267 minutes per week (Figure 8). The 2 participants who reportedly did not exercise at the start of the study (T12 and T6 injuries) averaged 58 (SD 24) and 157 (SD 61) minutes of exercise per week during the study. The participant with a C7 injury, who had not previously exercised in his home, averaged 48 (SD 14) minutes per week, and the participant who already had an adapted gym in his home averaged 52 (SD 18) minutes per week. From the EMG collected on the cloud server, we measured the total integrated EMG, which is linearly related to energy expenditure [37]. iEMG and inferred energy expenditure increased in proportion to the time spent on the app (Figure 9; r=0.86); that is, the more they used the app, the more energy they expended. In contrast, the maximum EMG level during the sessions, or peak EMG, did not correlate with the time spent on the app (r=0.040), as would be expected, because the peak value is fairly arbitrary—the goals of the games did not encourage them to try to hit their true MVC. Similar results were found for the racing game (r=0.86 for iEMG vs total session time) and boxing (r=0.57).
Figure 8. The average number of minutes spent per week using the app and exergaming by each participant.

Figure 9. Scatterplots indicating the correlation between time spent on app and energy expenditure, as measured by iEMG. iEMG: integrated electromyography.

Figure 10 shows that the minutes spent exergaming each week varied from week to week. From the group chat, participants indicated certain weeks that were busier and did not feel able to make more time for exercising. Participant S3 far exceeded other participants in minutes spent exergaming. This participant indicated through the group chat the most interest in the leaderboard and how to improve his rank in the leaderboard. He also expressed hesitation with allowing others to see him while exercising.

The percentage of time logged onto the app that was spent in the exergaming sessions ranged from 48% to 69% for S1, S2, and S3. S4 was the only participant who had hand mobility impairment and had to use his knuckles to tap the screen and had a home care helper to help with snapping electrodes to the sensors. By week 3, his efficiency reached 43%, and by week 8, his efficiency reached 58%.

Over the course of 8 weeks, 234 messages, comprising 20 conversations or threads, were sent over the WhatsApp group chat. The 4 participants reported a total of 18 issues and concerns about the WhatsApp group chat, 9 (50%) of which were related to the mobile app itself. These included issues regarding difficulty assigning sensors, games not working because the threshold was not set appropriately, and app crashing when Wi-Fi connectivity was lost, and once because of a billing issue with the cloud service that disabled app use for a day until service was restored. Most of these issues were resolved by week 2. Other nonapp-related issues included running out of the disposable EMG electrodes or batteries or not feeling physically well enough to exercise. There were a couple of conversations consisting of dozens of messages to welcome the participants to the group chat and encourage the participants to write to the group about any issues they had using the app. It was clear that in a few of the issues reported, the instructions simply needed to be made clearer at orientation (eg, the fact that multiplayer functionality was only enabled at that stage for the racing game); most of the other app-related issues were resolved by having a video chat to adjust the EMG thresholds during the first week of the study.
Figure 10. WOW-Mobile app usage over the 8-week period. (a) Total number of minutes spent on the app. (b) Number of minutes spent in exergaming sessions on the app. (c) Percent time on app spent exergaming.

**User Perceptions—Quantitative Responses**

The results from the questionnaire on the perceived usefulness of the WOW-Mobile app are presented in Table 5. Participants largely found the app to be useful. Participants reported that the app made it easy to track progress, increased motivation to exercise, and enabled participants to increase their level of physical activity. This information is presented in Table 5. Participants were also asked about the perceived ease of use of the WOW-Mobile app. Participants reported that the app was clear and easy to use. These data are presented in Table 6.

Finally, participants were asked about the usefulness of the various features of the app (Table 7). The highest rated game features were the single-player racing or spinning game and the boxing game. The lowest rated game was the resistance band game. The highest rated exercise features were the ability to monitor the heart rate and the ability to adjust EMG thresholds. The ability to monitor muscle activity was the lowest rated feature for all participants.

| Table 5. Perceived usefulness of the app on a Likert scale ranging from 1 to 5 (higher scores indicate stronger agreement). |
| Perceived usefulness                                                                 | Mean score (SD) |
| Using the mobile fitness app enabled me to increase my level of physical activity  | 4.25 (0.96)     |
| Using the mobile fitness app enabled me to reach my peak fitness levels             | 3.75 (0.5)      |
| Using the app improved my motivation to exercise                                   | 4.5 (1.0)       |
| Using the app enhanced the effectiveness of a workout session                      | 4.0 (0)         |
| Using the app made it easier to track my progress                                  | 4.7 (0.77)      |
| I found the app useful for improving, and then maintaining, fitness level          | 3.3 (0.5)       |

| Table 6. Perceived usability of the app on a Likert scale ranging from 1 to 5 (higher scores indicate stronger agreement). |
| Perceived usability                                                                 | Mean score (SD) |
| How to operate the app is clear                                                     | 4.5 (5.8)       |
| I found it easy to get the app to do what I want it to do                           | 4.0 (1.7)       |
| It would be easy for me to become skillful at using the app                         | 4.3 (1.2)       |
| Overall, I found the app easy to use                                               | 4.3 (1.2)       |
Table 7. Usefulness of various app features (both games and exercise monitoring features; ranked on a Likert scale from 1 to 5, with higher scores indicating more usefulness).

<table>
<thead>
<tr>
<th>Usefulness of app features</th>
<th>Mean score (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-player racing or spinning game</td>
<td>4.0 (1.2)</td>
</tr>
<tr>
<td>Boxing game</td>
<td>4.0 (1.2)</td>
</tr>
<tr>
<td>Resistance band game (Break-It-Like-Junior)</td>
<td>3.5 (1.0)</td>
</tr>
<tr>
<td>Multiplayer racing game</td>
<td>4.5 (1.0)</td>
</tr>
<tr>
<td>Leaderboard (seeing your ranking and score among the other app users)</td>
<td>4.5 (1.0)</td>
</tr>
<tr>
<td>Ability to monitor muscle activity</td>
<td>3.0 (0)</td>
</tr>
<tr>
<td>Ability to monitor heart rate</td>
<td>4.0 (1.2)</td>
</tr>
<tr>
<td>Flexibility to adjust EMG² (muscle activity) thresholds</td>
<td>4.0 (1.2)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>aEMG: electromyography.</td>
<td></td>
</tr>
</tbody>
</table>

User Perceptions—Qualitative Responses

The questionnaire also included open-ended responses. The participants reported that the most positive aspects of the app included monitoring their progress and that it keeps track of how much time was spent in each session, helped them to “exercise in an animated and engaging way,” and motivated them to work out. The most negative aspects of the app were reported to be glitches, app crashing, and that some of the games can be interpreted as being created for children not adults. There was one response to the free-response question: “Overall, I believe like anything, the app could use improvement, maybe look more modern, and include more features or different exercises but the fact that someone is creating an exercising app for people who are wheelchair bound is simply amazing.”

Discussion

Although mobile technology is being leveraged for fitness monitoring [38,39], and now includes exergaming [16,18], these apps are not tailored for individuals in wheelchairs. The exergaming apps that are available do not focus on upper limb exercises and are not equipped to track isometric contractions, as used in resistance exercises recommended for individuals in wheelchairs in at least 2 ways: (1) exergames by Garcia-Hernandez et al [40] are on a PC platform, whereas WOW-Mobile was designed to maximize the flexibility of where and when this system could be used to help overcome barriers to exercise; and (2) the games developed in the study by Garcia-Hernandez et al [40] do not require sustained isometric strengthening contractions, such as resistance arm band exercises that are recommended for CRT; rather, their games require short bursts of muscle contraction. The WOW-Mobile system achieved its design objectives of increasing the likelihood of improving fitness levels and providing individuals in wheelchairs with the independence and flexibility to work out in the convenience of their own home to do so regularly (Figure 7 and Figure 9—S1, S3, and S4). Analysis of the participants’ EMG indicated that when users increased their time on the app, they burned more calories. SDs in minutes of exercising per week ranged from 14 to 61 minutes, which, based on participant feedback, was because of variability in busyness from week to week. Even after drops in exercise, participants still tended to resume more typical levels of exercise (Figure 9), indicating that they were incorporating exercise into their lifestyle, not just letting it be a one-time spurt of commitment. The participants with paraplegia who had good hand mobility had more consistent percent time exercising, whereas the one participant with tetraplegia showed a logarithmic rise in time efficiency on the app (Figure 9). This learning curve pattern indicates that it took time to settle into a routine and become accustomed to using the WOW-Mobile system, but by week 3, he already reached similar levels of efficiency as the rest of the cohort. According to feedback from the perceived usability and usefulness questionnaire as well as on the mobile messaging app, the app was usable and exercised more motivating.

On the basis of the problems that were expressed on the group chat, the most problematic issues using the app were due to lost internet connectivity, assigning sensors incorrectly, or difficulty setting appropriate EMG thresholds for each game to ensure that the users were challenged to reach an appropriate effort level. We are currently working on developing an offline version of the app that does not require continuous cloud server communication and devising algorithms to automate the threshold setting process. We have also been improving the user interface to make the assignment of sensors more user-friendly.

The mobile app, while allowing participants to perform holistic upper limb exercises, did not explicitly facilitate the circuit training prescribed by our team and others. When playing the exergames, the users were motivated to reach high scores and did not necessarily pace themselves as would be done in a circuit training program guided by knowledgeable physical trainers. One way to overcome this limitation is to design the games such that compliance with the desired workout is measured and users gain higher scores for closer compliance with the workout. For example, for the racing game, the physical trainers could create their own sessions exercising for the prescribed duration and intensity levels. The participants could select these sessions as...
the ghost player in a multiplayer game, and the objective of the game would be to remain within a certain distance from the ghost player. The WOW-Mobile fitness app already has the basic functionality built in to carry out such a protocol. Future versions of the app will include an option to play the games in a preset sequence rather than the user choosing games and number of repetitions.

The multiplayer gaming and leaderboard features were designed to make exercise and mobile fitness feel like an activity that could be done in a community with friends. One limitation of the study is that the participants did not have much opportunity to build community with each other before beginning to use the app, nor were they given opportunities to get to know each other outside of using the app together, and therefore, the potential of these features to help motivate users to play the games, and therefore exercise more, could not be evaluated in this study. Despite the participants not knowing each other before the study, the participants with thoracic level injuries strongly agreed that the app motivated them to exercise. We observed that for one participant who had impaired hand mobility, using the app would take substantially more effort and tedium to use, for example, to tap the screen to navigate the app. Although we can only speculate from our pilot study over differences in perception by age, gender, level of injury, and access to exercise facilities at baseline, the results provide us more basis for hypotheses to test in the future. For example, given that the one participant with a cervical level injury consistently rated the app’s usefulness lowest out of all the participants, we would hypothesize for future studies that WOW-Mobile is effective for individuals whose lower mobility is impaired but not their hand mobility. In addition, the participants who only rated the app’s usefulness with 4s and 5s did not exercise regularly before the study. This is consistent with our hypothesis that WOW-Mobile helps individuals with lower mobility impairment to overcome barriers to exercise.

On average, participants rated the usefulness of all the features between agree and strongly agree (4.0–4.5), with the exception of the monitoring EMG, for which the average was 3.75/5. They expressed valuing the ability to monitor their heart rate on the app, but less so on muscle activity. This could be due to target heart rates being more common knowledge and people, in general, being more accustomed to seeing heart rate. Therefore, we plan to design a more reliable metric based on EMG, such as calories burned, in future versions of WOW-Mobile.

The participants reported agreeing or strongly agreeing that it was clear how to use the app and that the app was easy to use but were more neutral on getting the app to do when they wanted it to do. The latter is consistent with the issues that were reported on WhatsApp, which were either already resolved or related to app functionality that is tied to network connectivity and the requirement to be connected to their user account on the cloud. We plan to develop an offline mode in which users can still enjoy, albeit limited, functionality even when the connection to the cloud drops.

The barriers to exercising that the participants were able to overcome by using the WOW-Mobile system included lack of access to adapted gyms, transportation to physical therapy clinics or gyms, and cost of physical therapy or gym memberships. Furthermore, anecdotal evidence indicates that being able to exercise in the comfort and privacy of one’s own home helped the participants overcome self-consciousness with their disability [41]. For example, one participant wanted help with a problem setting threshold but was reluctant to do a video chat; this same participant was the only one who declined a photo or media release form. Other participants expressed wanting to know what they looked like while exercising and expressed discomfort with having to be transferred while others besides the regular personal assistant were around. The fact that all these participants spent between 89 and 267 minutes per week carrying out their workout in wheelchairs for 8 weeks indicates that mobile app–based EMG-driven exergaming is a promising approach to facilitate and encourage regular exercise for individuals in wheelchairs.

Conclusions
We have developed a mobile app–based fitness system that provides individuals in wheelchairs with a flexible way to carry out a goal-oriented, holistic workout with motivating feedback. We have bench tested the WOW-Mobile system and found the system to meet design specifications to support a circuit training workout that has been recommended for people with SCI and which supports individuals in wheelchairs to overcome existing barriers to regular exercise, including transportation and financial means to access gyms with adapted equipment and frequent and regular in-person visits with physical trainers. We also tested and verified the feasibility of individuals in wheelchairs using the WOW-Mobile system in their own homes. The participants who had thoracic level injuries and maintained hand mobility benefited most from WOW-Mobile and reported strong agreement with the overall ease of use of the app as well as the usefulness of the app in motivating them to exercise and enabling them to exercise more. As noted by one of the participants, mobile fitness tailored for individuals in wheelchairs is an unmet need and “the fact that someone is creating an exercising app for people who are wheelchair bound is simply amazing.”

Acknowledgments
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http://rehab.jmir.org/2021/1/e16054/
Conflicts of Interest
None declared.

Multimedia Appendix 1
Demonstration of connecting the wireless sensors.
[MP4 File (MP4 Video), 16672 KB - rehab_v8i1e16054_app1.mp4]

Multimedia Appendix 2
Demonstration of the high striker or resistance arm band exergame.
[MP4 File (MP4 Video), 35731 KB - rehab_v8i1e16054_app2.mp4]

Multimedia Appendix 3
Demonstration of the multiplayer racing or spinning exergame.
[MP4 File (MP4 Video), 29891 KB - rehab_v8i1e16054_app3.mp4]

Multimedia Appendix 4
Demonstration of the boxing exergame.
[MP4 File (MP4 Video), 60407 KB - rehab_v8i1e16054_app4.mp4]

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34. Pal A. Wheelchair exercise monitor development platform. : Scite Press; 2018 Presented at: 7th International Conference on Sensor Networks (SENSORNETS 2018); -; Madeira, Portugal p. 67-73 URL: https://www.scitepress.org/Link.aspx?id=0.5220/00066100000670073


Abbreviations

CRT: circuit resistance training
EMG: electromyography
iEMG: integrated electromyography
MVC: maximum voluntary contraction
SCI: spinal cord injury
WOW: Workout on Wheels

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One-to-One and Group-Based Teleconferencing for Falls Rehabilitation: Usability, Acceptability, and Feasibility Study

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Abstract

Background: Falls have implications for the health of older adults. Strength and balance interventions significantly reduce the risk of falls; however, patients seldom perform the dose of exercise that is required based on evidence. Health professionals play an important role in supporting older adults as they perform and progress in their exercises. Teleconferencing could enable health professionals to support patients more frequently, which is important in exercise behavior.

Objective: This study aims to examine the overall concept and acceptability of teleconferencing for the delivery of falls rehabilitation with health care professionals and older adults and to examine the usability, acceptability, and feasibility of teleconferencing delivery with health care professionals and patients.

Methods: There were 2 stages to the research: patient and public involvement workshops and usability and feasibility testing. A total of 2 workshops were conducted, one with 5 health care professionals and the other with 8 older adults from a community strength and balance exercise group. For usability and feasibility testing, we tested teleconferencing both one-to-one and in small groups on a smartphone with one falls service and their patients for 3 weeks. Semistructured interviews and focus groups were used to explore acceptability, usability, and feasibility. Focus groups were conducted with the service that used teleconferencing with patients and 2 other services that received only a demonstration of how teleconferencing works. Qualitative data were analyzed using the framework approach.

Results: In the workshops, the health care professionals thought that teleconferencing provided an opportunity to save travel time. Older adults thought that it could enable increased support. Safety is of key importance, and delivery needs to be carefully considered. Both older adults and health care professionals felt that it was important that technology did not eliminate face-to-face contact. There were concerns from older adults about the intrusiveness of technology. For the usability and feasibility testing, 7 patients and 3 health care professionals participated, with interviews conducted with 6 patients and a focus group with the health care team. Two additional teams (8 health professionals) took part in a demonstration and focus group. Barriers and facilitators were identified, with 5 barriers around reliability due to poor connectivity, cost of connectivity, safety concerns linked to positioning of equipment and connectivity, intrusiveness of technology, and resistance to group teleconferencing. Two facilitators focused on the positive benefits of increased support and monitoring and positive solutions for future improvements.
Conclusions: Teleconferencing as a way of delivering fall prevention interventions can be acceptable to older adults, patients, and health care professionals if it works effectively. Connectivity, where there is no Wi-Fi provision, is one of the largest issues. Therefore, local infrastructure needs to be improved. A larger usability study is required to establish whether better equipment for delivery improves usability.

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KEYWORDS
aged; postural balance; telerehabilitation; patient compliance; accidental falls; mobile phone

Introduction

Background
There are approximately 55,000 falls-related emergency hospital admissions in England among patients aged 65 years and older, and around a third of people aged 65 years and above fall each year [1], costing the National Health Service (NHS) £4.6 million (US $6.2 million) per day [1]. Strength and balance exercises have been proven to be effective in reducing the risk and rate of falls [2-4]. However, for these exercises to be effective, a minimum effective dose (3 times a week) must be reached and then maintained in the long term for sustained effects [3]. We know that the role of health care professionals is important in both motivating older adults and progressing their exercise to ensure that the exercises are challenging [5,6]. Currently, strength and balance programs delivered by NHS falls rehabilitation services are inadequate in dose [7], and most services see patients only once per week [7].

Teleconferencing could be an effective way of delivering evidence-based strength and balance exercises by providing increased contact with health care professionals. It has been demonstrated that introducing video consultations is complex and disrupts established processes and routines [8,9]. Concerns have been raised about technical and clinical quality, privacy, safety, and accountability [8,9]. The evidence base on remote consultations by video technology is increasing [10-12], and studies have reported positive benefits and similar satisfaction levels. However, studies that focus on the role of teleconferencing for fall prevention are sparse. Some studies have focused on the delivery of Tai Chi [13,14], and others have focused on other types of rehabilitation [15-17]. The systematic review by Kairy et al [15] examines the clinical outcomes, clinical process, health care utilization, and costs associated with telerehabilitation (therapy delivered through teleconferencing). Clinical outcomes of telerehabilitation programs were found to be as good if not better when compared with those of standard programs. In addition, adherence to telerehabilitation was found to be good. Other reviews have provided some potential but are still not conclusive [18]. Social networks and friendship have also been identified as important aspects of group telerehabilitation programs [19].

As health professionals do not need to travel (cost and time) to patients’ houses, teleconferencing could allow them to see patients more regularly than once a week, increasing exercise dose and motivation. We know that health professionals are an important source of motivation [5,6,20]. Strength and balance exercises could be delivered both one-to-one in patients’ homes or in groups. Some patients do not have the confidence or ability to attend face-to-face group exercise sessions [21]. It may be that being part of a small virtual group either increases confidence and ability to attend a face-to-face group session or enables adherence through long-term exercise and peer support available in the home [22].

Objectives
The aim of our study is to examine whether smartphone-based teleconferencing (linked to a television [TV] or screen) is usable, acceptable, and feasible for health professionals and older adults as a means of delivering evidence-based fall prevention strength and balance home exercise programs. Acceptability is a multifaceted construct that considers the extent to which people that deliver or receive a health care intervention consider it to be appropriate [23]. When referring to feasibility, we particularly focus on practicality (to what extent teleconferencing could be conducted with the intended participants using existing means, resources, and circumstances) and implementation (to what extent teleconferencing could be used to successfully deliver rehabilitation to intended participants) [24]. Usability focuses on whether a person can use it for its intended purpose [25]. Models such as the technology acceptance model (TAM), which focuses on whether a technology is perceived as useful and whether it is easy to use [26], are important when developing technological interventions and are considered within our study. We took a two-step approach to explore acceptability, usability, and feasibility.

Methods
Patient and Public Involvement Workshops
We held 2 patient and public involvement (PPI) workshops to gain initial feedback on teleconferencing:
1. Group of health professionals from a Manchester Falls Service
2. Group of community-dwelling older adults aged 60 and over years from an Age UK strength and balance falls exercise group

The teleconferencing involved using Skype on the smartphones of health professionals and patients and connecting the phones to either a screen or TV. We know that older adults feel more comfortable using technology they are familiar with [27], and therefore, we thought this would be more acceptable than specific teleconferencing equipment.

The health professional workshop was run by a researcher who was also an occupational therapist (OT) in a different falls team. The older adult workshop was run by the OT and the lead researcher for the project. In the workshops, we discussed the
initial concept of the technology with an explanation of why we thought it was important (perceived usefulness), what we were trying to achieve, and how teleconferencing could work for rehabilitation. We then connected the phone to a large screen (as would have been done for delivery) and demonstrated to the whole group what patients and health professionals would need to do and what they could see. We asked for feedback on the concept and whether participants (health professionals and older adults) thought health professionals and patients would be able to use it (perceived ease of use). Discussions on stands for smartphones and equipment used (whether to use Chromecast or a high-definition multimedia interface [HDMI] cable to connect the phone to a TV or screen) were included. Notes were taken on the feedback provided.

Contact with older adults and health professionals was classed as PPI rather than formal research. Therefore, we only collected aggregate details on gender, ethnicity, and previous experience of technology for participants and gender and clinical background for health care professionals.

**Usability and Feasibility Testing**

The research proposed in this stage was predominantly qualitative. This enables us to establish whether the technology is acceptable to patients and health professionals (qualitative methods) and assess its usability and feasibility in practice (technology testing) and to make improvements if required. The study was granted ethical approval by the North West Greater Manchester Central NHS Ethics Committee (integrated research application system: 205980, June 2016).

**Sampling Principles and Procedures**

Older adults at risk of falls (aged 50 years and above), identified through the current community falls rehabilitation services from one service in Manchester, were recruited, with the aim to recruit 20 participants. Participants were those who would usually be offered a home exercise program by the service and could be at any stage in their rehabilitation (eg, we wanted patients both at the start of their program and also further on in their program so that we could assess the feasibility of the delivery of most of the evidence-based program through teleconferencing). Older adults who were unable to follow instructions and those with severe visual or hearing impairment were excluded. At this point, there were no other exclusion criteria. The lead researcher provided technical support to patients and health professionals during the study period.

**The Intervention**

**The Technology**

For testing, we used Samsung Galaxy S4 phones and *pay as you go* sim cards and 4G networks, and where possible, we connected them to the patients’ Wi-Fi networks. Both the health professional and patient had a phone provided by us that they connected to either their own TV or a provided screen either using a HDMI cable or through Google Chromecast. When the device was used for teleconferencing, it could be placed in a docking station, which then connected to the television.

The technology was tested using either 4G-enabled phones or by providing broadband at patients’ homes. The broadband (where not already in place) was paid for and set up by the research team with no cost to the patient. The smartphones and docking station were provided by the research team, and compatible screens were also made available. They were also given a wireless headset to ensure they could hear each other during the videocall. We used Skype for both individual and group-based virtual home exercise in the patients’ own homes, with health professionals delivering the exercise program from their offices.

**The Exercise**

Patients were offered standard service for 2 weeks (to ensure safety) before usability testing. They were then offered the same evidence-based home exercise program that is delivered through standard service, but it was delivered through the technology virtually. Patients received additional contact (twice a week rather than once a week) during the testing period. The health professional delivered the evidence-based Otago exercises [28], with additional exercises from the evidence-based falls management exercise (FaME) program where appropriate [29].

The technology was used to deliver the following:

1. One-to-one home-based exercise twice over a period of 2 weeks for an hour through the smartphone system.
2. A group-based strength and balance program (2-3 patients) once over a period of 1 week for an hour through the smartphone system. The health professional was able to see all the patients, and the patients were able to see each other.

The researcher was present with the patients at the time of the exercise session and supported the patient to use the technology where required.

**Measurements**

**Usability**

This included recording issues the health professional and the older adults faced with regard to the technology throughout the testing period (issue-log or field notes).

We explored usability issues such as setting up and connecting the technology and accessing Skype, requirement for internet access or testing of 4G through mobile phone and whether teleconferencing would connect, and whether it was reliable through the use of 4G technology rather than Wi-Fi. The positioning of the technology for delivery of exercise both in the patients’ homes and at the offices of health professionals.

**Feasibility**

The size of the groups receiving the intervention (ie, the ideal number of patients) and the types of exercise that could be delivered through the smartphone system were considered.

**Interviews and Focus Groups**

Health professionals from 3 falls services in Manchester were recruited to participate in 3 focus groups following the testing period. We chose focus groups, as each group of health professionals was a team delivering a service together. The focus groups allowed them to discuss their experiences and “bounce off” each other, eliciting more experiences and rich
data. All members of the staff (n=17) in each team were given study information by their team leader and asked if they were available for a focus group at their place of work.

The service involved in the testing gave direct feedback on their experiences of using the technology. The other two services received a demonstration of the technology and were asked to give their feedback based on a similar interview schedule (Table 1).

Older adults who participated took part in a one-to-one interview from their own homes. The questions in the interview and focus group schedules were based on FAIl Repository for the design of Smart and sElf-adaptive Environments prolonging Independent livinG (FARSEEING) [30] consortium guidelines (a European-funded project that examined the design and implementation of technologies around falls) and the TAM [26]. The following key areas were explored in relation to the hardware (phone and setup) and teleconferencing (Skype): ease of use, adaption of use, reliability, choice, and control. We explored whether it was acceptable and feasible for patients to receive their program in this way and whether health professionals were willing to deliver this way, and preference for group or individual virtual exercise was also explored. Open-ended questions were designed to elicit a wide-ranging response.
Table 1. Interview and focus group schedule.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Acceptability</th>
<th>FARSEEING(^a) guideline</th>
<th>TAM(^b)</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Older adults' interview schedule</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What did you like or dislike about using a smartphone to exercise with the health professional?</td>
<td>✓</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Adaption of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were there any issues with using a smartphone to participate in your exercise sessions?</td>
<td>___d</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Adaption of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Were there any issues with space to do the exercises?</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>Did you feel safe?</td>
<td>—</td>
<td>• Choice and control</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>• Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How did it compare to the normal program delivered in person by the health professional?</td>
<td>✓</td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>What did you think about exercising in a small group?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>Were there any issues?</td>
<td>—</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did you enjoy it?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
<tr>
<td>What did you enjoy or dislike?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
<tr>
<td>Would you exercise in a group without a health professional?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>Did you prefer exercising one-to-one or in a group?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
<tr>
<td>How did you feel about being provided with broadband? (where applicable)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Health professionals’ focus group schedule</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teleconferencing and taking part in the exercises using a smartphone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALL(^c): What do you think about delivering exercise virtually?</td>
<td>✓</td>
<td>• Reliability</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>• Choice and control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Perceived ease of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you think the barriers or issues are?</td>
<td>—</td>
<td>• Reliability</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Choice and control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ease of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Adaption of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What do you think the advantages are?</td>
<td>—</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
<tr>
<td>CFS(^f): How was your experience of delivering exercises virtually?</td>
<td>—</td>
<td>• Reliability</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Choice and control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Ease of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Adaption of use</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFS: Were there any exercises that you could not deliver?</td>
<td>—</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Were you able to adapt the exercises?</td>
<td>—</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Did you feel that there were safety issues?</td>
<td>—</td>
<td>• Reliability</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>• Choice and control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) FARSEEING: Framework for assessing the Usability of Electronic Information.

\(^b\) TAM: Technology Acceptance Model.

\(^c\) JMIR: JOtM, J. Med. Internet. Res. 2019 | vol. 21 | iss. 7 | e19690 | p.36

http://rehab.jmir.org/2021/1/e19690/
<table>
<thead>
<tr>
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<th>Acceptability</th>
<th>FARSEEING(^a) guideline</th>
<th>TAM(^b)</th>
<th>Feasibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFS: Did you feel that patients were confident in carrying out exercises in this way?</td>
<td>—</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: For which patient group do you feel that this intervention would be appropriate?</td>
<td>—</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Were there any issues with connecting the technology?</td>
<td>—</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Did you feel that you had enough technical support?</td>
<td>—</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Were there any issues with Wi-Fi access or reliability?</td>
<td>—</td>
<td>• Reliability</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Were there any issues with having enough space or room to deliver the exercises from your office?</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Did you feel that patients were safe?</td>
<td>—</td>
<td>• Reliability</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: How did it compare to delivering your normal home exercise service?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>ALL: What do you think about using technology to deliver exercise virtually to a small group?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Were there any issues with using a smartphone to deliver to small groups?</td>
<td>—</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: Did you feel that it was beneficial to patients. If so, how?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
<tr>
<td>CFS: Were there any issues with delivering in this way?</td>
<td>—</td>
<td>• Ease of use</td>
<td>• Perceived ease of use</td>
<td>✓</td>
</tr>
<tr>
<td>CFS: What did the patients think of it?</td>
<td>✓</td>
<td>—</td>
<td>• Perceived usefulness</td>
<td>—</td>
</tr>
</tbody>
</table>

**Overall**

| Would you use a smartphone again or continue to use it if you could?                                                                                                                                   | ✓             | —                           | • Perceived usefulness | ✓           |
| If not, why not and which parts of using a smartphone did you not like?                                                                                                                                | —             | • Ease of use               | • Perceived usefulness | ✓           |
| What needs to be improved for using this system in your routine practice?                                                                                                                             | —             | • Ease of use               | • Perceived ease of use | ✓           |

\(^a\)FARSEEING: Fall Repository for the design of Smart and self-adaptive Environments prolonging Independent living

\(^b\)TAM: technology acceptance model.

\(^c\)✓: the question relates to that concept.

\(^d\)__: the concept does not apply to the question.

\(^e\)ALL: all teams were asked, including the ones given a demonstration.

\(^f\)CFS: the identifier for the team who did the actual testing.

**Analysis**

Follow-up interviews with patients, focus group data with health professionals, and field notes were analyzed together using framework analysis [31]. This is a method of research that provides a clear structure for the coding. NVivo 11 qualitative data analysis software (QSR International) was used to manage the data. The validity of the analysis was checked by returning to the data once themes were identified and also through independent coding conducted by a second researcher on a sample of transcripts. Two researchers conducted discussions around the codes that emerged. This approach ensures rigor [32] by checking the coding of the data. Data from the issue-logs were collated, summarized, and coded within the qualitative data and used to provide triangulation for the focus group or interview data.
Results

Initial Consultation

Initial informal consultation with 3 services indicated that teleconferencing could aid delivery of rehabilitation, reduce the commute time of health care professionals and their chance of being caught up in traffic, and provide extra support to patients. Health professionals suggested that any intervention had to be carefully planned due to safety issues.

PPI Workshops

Demographics of the older adults and health professionals in the workshops are reported in more depth in a previous study [33]. We recruited 5 health professionals, including 2 physiotherapists, 1 OT, 1 rehabilitation assistant, and 1 assistant practitioner. A total of 8 older adults were recruited, 6 of whom were female and all were White British. Two of the older adults participating in the workshop had previously used technology such as smartphones, tablets, or computers.

Health Professional Workshop

The workshop with health professionals found delivering exercise safely was the priority. Health professionals felt that a risk assessment of patients’ home environment would be required to ensure that it was safe to exercise and that the equipment was positioned correctly, for example, to ensure that the equipment was positioned where patients could access support during their exercises. They also felt that there were some challenges in delivering exercises through teleconferencing and that they may need to be adapted to be completed remotely.

Practitioners did not want to replace face-to-face consultations with only remote monitoring, as they felt that it is important to have personal contact with the patients. Health professionals felt that face-to-face contact enabled other issues to be identified (non-exercise related) and was also important to ensure that patients conduct exercises safely. They had no preference for the different types of stands or headsets for delivery.

Older Adults’ Workshop

Older people did not want to lose their face-to-face contact with health professionals completely and expressed the fear that use of technology could mean that patients would no longer get visits from a health professional. Some older adults stated that the health care professional is the only person they see all week. They thought that extra virtual sessions with health professionals could provide opportunities to reduce loneliness and isolation.

Some older adults stated that they would not like any technology within their homes; they felt that with the presence of technology, their homes would not feel like a home, and they also found the technology intimidating.

Older adults in the workshop had no preference for the different types of stands or headsets, and they were quite happy to wear the headsets; in fact, they quite liked the idea of doing so, as it brought back memories from working.

Usability and Feasibility Study

A total of 7 patients (4 men) with a mean age of 77 years (range: 64-92) participated, and of these patients, 6 agreed to be interviewed; for one interview, the participant’s son was also present. Only 2 of the participants who took part already owned a smartphone. Only 2 of the patients already had Wi-Fi, and I agreed to let us install Wi-Fi to enable them to use teleconferencing. A total of 11 health professionals took part in the focus groups; 8 were women, 9 were physiotherapists, 1 was a nurse, and 1 was an OT (see the study by Hawley-Hague et al [33] for further demographics).

Data were summarized under barriers and facilitators, with 7 further subthemes. We have also linked themes to the theoretical framework (Table 2). Two overarching themes related to smartphone were established and are discussed in a separate paper where patients used a smartphone app (see the study by Hawley-Hague et al [33]). Some themes only occur for either patients or health professionals.
Table 2. Themes and subthemes from the interviews and focus groups.

<table>
<thead>
<tr>
<th>Theme and subtheme</th>
<th>Theoretical framework</th>
<th>Patients</th>
<th>Health care professionals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barriers</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Poor connectivity</td>
<td>• Reliability</td>
<td>“If you’re not here to rectify it, I wouldn’t know what to do, would I?” [Male, aged 92 years]</td>
<td>“When it worked it was good, but I must say after that session where it overheated so many times, following that I thought what is it, are we going to have that again. So I was very relieved to get through a session where it went all the way through” [Female, physiotherapist, S1]</td>
</tr>
<tr>
<td></td>
<td>• Perceived usefulness</td>
<td>“So last time we got at least ten minutes, that’s the most we ever got, wasn’t it?” [Female, aged 69 years]</td>
<td>“They drained when we were actually using it. So battery life wasn’t good enough to do the actual full exercise programme” [Female, occupational therapist, S1]</td>
</tr>
<tr>
<td></td>
<td>• Feasibility</td>
<td>“It was just unfortunate that it was that patient where the phone froze on numerous occasions…then it was the secondary kind of safety issue of it freezes in the middle of the session” [Female, physiotherapist, S1]</td>
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<tr>
<td>Cost of connectivity</td>
<td>• Feasibility</td>
<td>“It’s the expense of getting the landline as well as getting the broadband…you’ve got to have broadband and we’re going to charge you bom-bom-bom-bom, whatever it is, I didn’t like so I got rid of it” [Male, aged 82]</td>
<td>“It didn’t work as well, connectivity…I don’t think you could do it with 4G really” [Female, physiotherapist, S1]</td>
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<td></td>
<td>• Acceptability</td>
<td>“we’d still have to pay the rental…” [Female, aged 69]</td>
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<td>Safety concerns</td>
<td>• Feasibility</td>
<td>—</td>
<td>“I had some concerns also about safety…I’d have thought if we’re doing a longer term study you wouldn’t be there, and some of the positioning that the equipment would be in wasn’t necessarily as safe for the patients…” [Female, physiotherapist, S1]</td>
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<td></td>
<td>• Perceived usefulness</td>
<td>—</td>
<td>“Because things like when we went to feet, we couldn’t see feet…Yeah. It was those things that I hadn’t anticipat-ed until we actually tried it…things like you couldn’t see if they had matching black socks then.” [Female, physiotherapist, S1]</td>
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<td></td>
<td>• Perceived ease of use</td>
<td>—</td>
<td>“…and I was trying to move so that I could actually see what was important, but then to get two people doing that was quite tricky. I couldn’t move them around” [Female, physiotherapist, S1]</td>
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<tr>
<td>Intrusiveness of the technology</td>
<td>• Adaption of use</td>
<td>“To leave something perma-nent it’s got to have its place like the television” [Male, aged 82]</td>
<td>“I think the other thing that frightened the patients was the amount of equipment that came in, like the screens and the cables and that sort of thing. It is kind of intrusive into a person’s property” [Female, physiotherapist, S1]</td>
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<td>Theme and subtheme</td>
<td>Theoretical framework</td>
<td>Quotes</td>
<td>Health care professionals</td>
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<tr>
<td>Group teleconferencing</td>
<td>• Feasibility</td>
<td>“I think you’ve got to be a certain type of person to do a group thing and I’m not that type of person actually, I just prefer to do it my way, my time, when I want, because if you’re doing it with a group you’re tied to however many number’s in the group” [Male, aged 82]</td>
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<td>• Acceptability</td>
<td>“Probably on my own to be honest but I was willing to give it a go testing that technology” [Male, aged 64]</td>
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<td>“If you deliver a one-to-one on the screen, that’s a fantastic idea. And I think it would relieve our time, the patient’s time. I think you’re kind of creating space...when we go and do a one to one at someone’s house you’ve got travelling time, you’ve got time in the house” [Male, physiotherapist, S2]</td>
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<td>“More reinforcement, isn’t it? So that’s good...monitor their adherence to the programme. Potentially less clinician time.” [Female, physiotherapist, S3]</td>
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<td>“We often find on discharge that we’ve had voluntary drivers to bring them to groups and things, but then that’s not available on discharge; so people that would happily come out can no longer come out. So they would love to carry on exercising in a group, so they would fit into that criteria” [Female, physiotherapist, S3]</td>
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**Facilitators**

<table>
<thead>
<tr>
<th>Positive solutions</th>
<th>Feasibility</th>
<th>Acceptability</th>
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<th>Acceptability</th>
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<tbody>
<tr>
<td>Increased support or monitoring</td>
<td>• Perceived usefulness</td>
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<td>• Acceptability</td>
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<td></td>
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<td>“Oh yeah, it’s nice...yeah, it’s like being at a group” [Male, aged 74]</td>
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*a*: the theme did not occur.
Barriers

Poor Connectivity

The reliability of teleconferencing was a very important issue, and reliability was threatened by a number of issues related to the connectivity of the phone during teleconferencing. One of the issues that occurred was overheating of the device during teleconferencing, which occurred mostly when testing the phone over 3/4G networks. This issue caused anxiety in health professionals. The patients were not as concerned as the health professionals, as a member of the research team was with them; however, they discussed the implications of what they would do if they were alone.

The battery life also seemed to be poor, and we think this was related to overheating due to poor connectivity. When the phones did not overheat, they froze during the teleconferencing, and this also caused concern, particularly for patient safety.

The lack of connectivity did not only cause the phone to overheat or freeze but also caused Skype sessions to suddenly switch off. We tested other forms of teleconferencing, such as Google Hangouts and WhatsApp video calling, but these performed more poorly in places with poor connectivity. In one patient’s house, the reception was very poor, and we never managed to get to the end of a full rehabilitation session without the phone being frozen or the Skype session being disconnected.

Cost of Connectivity

As part of the study, we offered to fund broadband connections if needed. When exploring broadband as a solution to connectivity issues, we learned that a large number of patients do not have landlines; therefore, we could not provide broadband connections for these patients without disruption. In some cases, there was resistance to broadband even when we offered to provide it because of the cost that would need to be sustained once the study had finished. One patient previously had broadband but stopped it because of the cost. Some patients had their landlines taken out due to extra cost because they had mobile phones (even if not smartphones).

Safety Concerns

We have already outlined how poor connectivity caused issues with teleconferencing and concerns over safety. However, there were other practical safety issues around delivering teleconferencing through the phone.

There were concerns over the positioning of the equipment. The majority of patients conducted their exercises in their kitchen (using the kitchen worktop for support), and sometimes, they faced issues with finding enough space and room. We could not use their TVs as originally planned and had to use a separate screen. We used the built-in cameras of the smartphones and found that placing the phone on top of the refrigerator often gave the best view. However, placing the phone on the refrigerator caused other safety issues and would have required patients with balance issues to reach up in the absence of the researcher.

There were issues not only with positioning but also with view and contrast. If patients wore black trousers and black shoes, it was difficult to see their feet, and the room’s source of light also affected the view and what the health professional could see. This became a significant issue with group teleconferencing, as the picture of each person became smaller with more people on the screen. Issues with sound were also observed when we tested group teleconferencing (2 patients and the health professional). This was exacerbated by the time lag in Skype and led to patients talking over each other. These were the issues that were predominantly highlighted by health professionals and did not seem to concern patients.

Intrusiveness of the Technology

In addition to positioning and safety, there were issues with the intrusiveness of the technology. Originally, we wanted to use the patients’ own TVs for teleconferencing, but as most patients conducted their exercises in the kitchen, this was not feasible; therefore, screens were provided. The intrusiveness of the equipment was raised as an issue by the health professionals. One patient also discussed the worry that the equipment could be seen from his front window and that it could cause a risk of a break-in. He felt that participants had to feel that the equipment had a specific place for it not to be intrusive. However, most patients did not mind having the equipment in their house. Health professionals stated that this could become an issue if we tested it with more patients for a longer period.

Group Teleconferencing

Only 2 patients were able to take part in group teleconferencing, as we needed 2 patients with broadband to be recruited at the same time for it to be reliable. We tried group teleconferencing using 3/4G, which would not connect and thus was not feasible. However, we did discuss group teleconferencing with all patients who participated. Some of the patients felt that they were not “group people,” whether the group met face-to-face or virtually, although all participants agreed to test it for us. There were increased safety issues related to group teleconferencing in terms of view and sound. The service we worked with did offer group sessions, and only 2 of the patients recruited for the testing chose to attend a face-to-face group as well as perform their exercises at home.

Facilitators

Increased Support or Monitoring

Health professionals saw the idea of teleconferencing as a time-saving intervention with the potential to save travel time, which enabled them to invest that time back into patients. They also saw it as another tool to enable them to monitor patients’ adherence to their program and give them more support. During the follow-up phase of rehabilitation (where the health professional did not see the patient every week), they felt that the technology would enable them to give more input than a telephone call, allowing them to check technique. It would also enable the health professional to check up on the patients remotely and then see them face-to-face if required. Group teleconferencing also provided an opportunity for group support that patients would not normally get when based at home. From the 2 patients who took part in the group teleconferencing, we received positive feedback, despite one being uncertain about groups. Despite their initial anxiety, this
patient enjoyed the group sessions and went on to actually attend a face-to-face group exercise class. Health professionals could see the potential benefits of group teleconferencing for tackling social isolation and building confidence to attend a face-to-face group session. They also discussed how group teleconferencing could provide support through follow-on opportunities where transport was prohibitive to attending face-to-face follow-on groups. Teleconferencing provided an opportunity for other support as several patients went on to explore options for skyping family and friends.

Positive Solutions
Health professionals came up with active solutions for issues with teleconferencing, such as positioning of the equipment and the view of patients. They suggested getting cameras that could rotate so that the patient would not have to reposition them.

They discussed the types of patients it would work with, and that it would be important to ensure that technique was right face-to-face first before delivering virtual support and checking technique. If patients were given the right combination of support (a mix of face-to-face and virtual), they would not perceive a safety issue.

Discussion
Principal Findings
Using teleconferencing for the delivery of rehabilitation exercises for falls prevention seemed to offer more barriers than facilitators. However, the barriers are not insurmountable if we have better connectivity and equipment. The original aim was to make teleconferencing accessible and easy to use by using existing equipment (eg, smartphones’ cameras). Although the current technology system is acceptable (perceived usefulness) to health professionals and patients and adequate for follow-up support calls, it is not adequate for the delivery of exercises (not easy to use, feasible, or reliable) [26]. Phones overheated, there was poor connectivity where there was no Wi-Fi, and the view was not adequate for the delivery of new exercises. Issues highlighted around ease of use were predominantly related to the smartphone camera and positioning. The only issue raised with the software (Skype) was the view and sound during group teleconferencing, and the reliability of the teleconferencing was affected by connectivity regardless of the platform. Further equipment is required to enable the safe delivery of exercises to patients.

Overall, participants and health professionals in the workshops and usability testing could see some benefits of teleconferencing in terms of additional support that could be provided and better utility of resources, for example, travel time (perceived usefulness and acceptability). Increased contact and support was identified as the main facilitator for teleconferencing in both the workshops and usability testing and has been identified as important in previous studies [19], and it has also previously been found to lead to higher levels of adherence [15]. We know from other exercise studies and behavioral theory, such as the Theory of Planned Behavior, that social support or social norms (perception that the health professional thinks it is a good thing to do) from health professionals is important to exercise behavior [5,34].

Some of the older adults in the workshop and patients in the usability testing did have some concerns about bringing the technology in to their homes and the technology being intrusive (feasibility), which is something often found in the literature [27]. This was one of the reasons that we tried to focus on technology that patients would already have, for example, connecting phones to existing TVs. However, the location of the TV was not always the best place for the patient to exercise; therefore, separate screens were provided.

Patients who took part in the usability and feasibility testing at no point suggested that they would prefer face-to-face delivery or showed fear that technology would replace human interaction (acceptability and perceived usefulness), which is something often cited in the literature [27,35] and raised by older adults in the PPI workshop. Battery life was one of the other issues raised in the usability testing, and this was especially an issue when the phone was under high use (reliability). Battery life is a recurring issue in usability studies using smartphones [36,37]. The phones used have been upgraded for subsequent studies using smartphones.

In the usability and feasibility study, the main issue within the UK context was the lack of good 4G connectivity. This was particularly an issue in some of the more deprived areas of Manchester, where the connectivity was very poor (reliability and feasibility). It seems that due to socioeconomic reasons, patients had decided to have landlines removed and only used mobile phones (often not smartphones). This raises issues related to digital exclusion, an issue already associated with older adults and those who are on lower incomes [38]. In the current climate where rehabilitation is being delivered remotely because of the COVID 19 pandemic, there are concerns that patients will be excluded because they cannot afford Wi-Fi or a suitable device. They may be excluded because they do not have the skills to use the device even if they are provided with one (digital literacy), as our patients were provided with a large amount of support from the research team. They may have physical, cognitive, and sensory impairments or language barriers that make using technology challenging, particularly if they live alone [39].

Recruitment of health professionals covered 3 different teams in the workshops and usability and feasibility testing, but only 1 team used the technology in practice. We found that the teams that only had the technology demonstrated to them (service 2 and 3) but did not actually use it in practice were more positive about its use (perceived usefulness and acceptability) and generated further ideas around other functionality. In contrast, those who had used the technology (service one) identified more barriers, particularly because the technology was not reliable, but rather than being negative or resistive to technology, they also proposed potential solutions and implementation suggestions (adding another rotating camera).

Limitations
There were limitations to the study during both the workshops and usability and feasibility study. During the workshop, we...
only illustrated how teleconferencing and the equipment would work, showing the patients and health professionals and older adults what would be seen. However, we did not demonstrate a full session. We did not ask health professionals to deliver an exercise session or ask the older adults to take part in one. This led to some issues not being identified until the usability testing that could have been preempted, such as the challenges related to the view from the phone camera.

At this point, the workshop was conducted with community-dwelling older adults and not patients; therefore, the participants were less frail and complex. It could be argued that they were two different populations, which may have influenced the feedback given. However, we would argue that it was a strength to represent a wide variety of older adults’ views. In both the workshops and the usability study, we had a good representation of gender across the older adults, patients, and health professionals.

For the usability and feasibility study, recruitment took longer than anticipated; therefore, a much smaller number of patients were recruited than initially planned. We were also unable to test group teleconferencing effectively, as only one set of patients had Wi-Fi at the same time. However, recruited participants represented a good mix of patients in terms of comorbidities, age, gender, and previous technology experience (some with experience of smartphones and some with no experience). None of the participants had previously used Skype or teleconferencing before the study.

The time period for testing the technology was short and may not have identified all the usability issues. If we had established a longer testing period, then we may have asked the patients to exercise alone using the technology without the presence of someone from the research team. However, during the testing period, we established that with the current technological setup, using the equipment alone would not have been safe.

Conclusions

Overall, we established that teleconferencing as a way of delivering falls rehabilitation can be acceptable to this group of patients and health professionals if it works effectively. There is a lack of research on smartphone-based teleconferencing interventions for the delivery of falls prevention exercise programs.

A larger usability and feasibility testing study is required to establish whether better equipment for delivery improves usability and makes delivery more feasible. The intervention can only be effectively delivered in patients’ homes where there is Wi-Fi. The options for delivery still need further investigation, as it is clear from testing that in normal circumstances, teleconferencing cannot be used as a full alternative to face-to-face delivery and can only be used to reduce face-to-face visits and to enhance current care. This study provides important information to health professionals now having to deliver care remotely because of the COVID-19 pandemic. In its current form, although it could possibly be a suitable delivery method for some older adults (those who are able to conduct their exercises without the requirement of physical correction by the health professional) because of connectivity issues, it can only be a suitable option for some patients, not all. The intervention may work more effectively in other countries, such as in the Nordic countries where Wi-Fi is more widely available.

Acknowledgments

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Authors’ Contributions

HH led the research project and its design, has managed the study overall, and has led the writing of the manuscript. C Tacconi and SM provided technical support and advised on the setup and the manuscript. JH, LC, C Todd, and SM provided scientific advice around the design of the study and commented on the manuscript. EM led the PPI work and gave advice on the operationalization of the study and commented on the manuscript.

Conflicts of Interest

C Tacconi owns a share in the spin-off company of the University of Bologna, mHealth Technologies srl. SM owns a share in the spin-off company of the University of Bologna, mHealth Technologies srl. LC owns a share in the spin-off company of the University of Bologna, mHealth Technologies srl.

References


Abbreviations

FaME: falls management exercise
FARSEEING: FAll Repository for the design of Smart and sElf-adaptive Environments prolonging Independent lvingG
HDMI: high-definition multimedia interface
NHS: National Health Service
OT: occupational therapist
PPI: patient and public involvement
TAM: technology acceptance model
TV: television

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