Feasibility of a real-world digital hybrid pulmonary rehabilitation model using a smartphone app

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Shareable abstract (@ERSpublications)
Hybrid PR, using a digital app to support standard pulmonary rehabilitation, does not reduce scheduled pulmonary rehabilitation sessions. Poor digital literacy is an important barrier to implementation of hybrid PR in practice. https://bit.ly/4dMdNVB

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Abstract

Background There is interest in digital technology-enabled models of pulmonary rehabilitation (Digital-PR) as a means of increasing capacity, uptake and accessibility. However, there are little data on real-world implementation or how Digital-PR could support other models of pulmonary rehabilitation delivery.

Methods We conducted a mixed-methods, feasibility study to evaluate the acceptability of a hybrid model of pulmonary rehabilitation (Hybrid-PR) blending Digital-PR with traditional, supervised pulmonary rehabilitation (PR). To determine acceptability, we measured engagement and use of the app and conducted patient interviews. We assessed differences in PR completion, number of scheduled sessions and staff time between Hybrid-PR and a propensity-matched control group attending PR without Digital-PR (Control-PR).

Results Of 69 people undergoing Hybrid-PR, 87% opted for in-person, centre-based care and 13% for home-based care (10% supported by video-teleconferencing, 3% supported by telephone). 86% activated Digital-PR at least once, but only 35% activated regularly (at least weekly for 8 weeks). 88% never accessed the exercise components of Digital-PR. There were no significant differences in PR completion rates, number of supervised PR sessions, nor staff time in Hybrid-PR when compared to Control-PR. Both patients and staff identified digital literacy, limited flexibility to adapt/tailor Digital-PR and increased time-commitment as potential barriers.

Conclusion Hybrid-PR was not considered acceptable due to intervention fidelity and limited patient engagement with Digital-PR. Hybrid-PR was not associated with reduction in scheduled supervised sessions. Poor digital literacy is an important barrier to implementation of Digital-PR in the real-world setting.

Background

Pulmonary rehabilitation (PR) is a widely recommended, supervised programme of individualised exercise training and education that alleviates breathlessness and enhances exercise capacity and quality of life in people with chronic respiratory disease [1]. The preferred delivery model, with the best-established evidence base, is supervised in-person, centre-based PR (Centre-PR) [1]. However, given modest uptake

and completion rates, as well as the need to increase capacity [2, 3], there is growing interest in alternative models of PR delivery [1–5].

New models of PR delivery using digital and web-based applications (Digital-PR) have been proposed as a way of increasing capacity, uptake and accessibility [4, 6]. The evidence-base for digital-based PR remains in its infancy, with previous studies largely focused on Digital-PR as an alternative to or replacement for Centre-PR [7–9] or combining Centre-PR with a shared decision aid, consisting of coaching videos and a chat function [10]. A common methodological issue was selection bias with the recruitment of digitally literate participants. There are little data on the real-world implementation of Digital-PR.

Clinical guidelines increasingly suggest Digital-PR as an alternative for those who cannot attend Centre-PR [1–4]. However, this limited indication may restrict the potential benefits and utility of Digital-PR. To date, there is a paucity of data investigating how digital interventions could support (rather than replace) Centre-PR.

We conducted a feasibility study to explore how Digital-PR would be used in the real-world PR setting using a hybrid PR model that blends Digital-PR with supervised PR. This model may improve the accessibility and flexibility of PR, whilst maintaining the benefits of direct supervision from skilled staff. We hypothesised that 1) patients might use Digital-PR as an adjunct to an existing PR model through additional home-based exercise and educational sessions, 2) patients might use Digital-PR in place of some in-person PR sessions, reducing burden on in-person services, and 3) patients might switch to Digital-PR as an alternative PR delivery model to in-person-PR, reducing the amount of required staff-supervision and, in turn, increasing service capacity.

The aims of this study were to 1) evaluate the feasibility of delivering Hybrid-PR by blending Digital-PR using a smartphone app with traditional, supervised-PR in a real-world clinical setting, 2) evaluate if participants completing Hybrid-PR would transition to Digital-PR only, 3) assess the fidelity of Digital-PR by measuring app activation and usage, 4) compare outcomes between Hybrid-PR and a cohort undergoing PR without access to Digital-PR (Control-PR) including PR completion, staff time and number of supervised sessions, and 5) measure patient acceptability and staff experience of Hybrid-PR.

Materials and methods

Study design

The study was a prospective single-centre, feasibility study evaluating the acceptability of "Hybrid-PR" in a real-world setting. We measured clinical outcomes of Hybrid-PR against a retrospective propensity-score matched cohort of patients undergoing PR without access to Digital-PR (Control-PR). Participants in both Hybrid-PR and Control-PR were offered in-person assessments before and after PR. A nested qualitative study investigated the acceptability of Hybrid-PR from the perspective of participants and PR clinicians. The study received approval from the Wales Research Ethics Committee 6 (23/WA/009) and the Health Research Authority on 29 March 2023 and registered on ClinicalTrials.gov (NCT05881590).

Participants

Hybrid-PR group

Participants in Hybrid-PR were prospectively recruited from the Harefield Pulmonary Rehabilitation service in northwest London between 4 May 2023 and 24 August 2023. All participants provided written, informed consent. Inclusion criteria were as follows: 1) aged 18 years or over; 2) grade 2–5 on the Medical Research Council dyspnoea scale and referred for PR; 3) willing and have capacity to take part in the trial. People with clear contraindications to exercise (*e.g.* unstable cardiac disease) were excluded.

All participants in Hybrid-PR were first offered a supervised in-person, centre-based PR programme (Centre-PR), consisting of two supervised exercise and education sessions per week for 8 weeks. This has been described in detail previously [11]. Those declining Centre-PR were offered an alternative 8-week home-based PR programme supervised either by real-time video-conferencing twice a week [12] (Video-PR) or by weekly telephone calls [13] (Home-PR).

All participants in Hybrid-PR were offered Digital PR, delivered using the Active^{+}me REMOTE app (Aseptika Ltd, St Ives, UK), a UKCA/CE class I-approved smartphone app. If potential study participants did not have access to a smartphone, they were offered a pre-paid phone with internet access for the study. The Active^{+}me REMOTE app has previously been used successfully in cardiac rehabilitation (CR) [14]. The app allows logging of independent exercise sessions, symptoms and medication, Bluetooth connection to pulse oximeter or manual logging of oxygen saturation (S_{pO_2}), step counting, access to pre-recorded

exercise classes delivered by a physiotherapist, and educational sessions with a read aloud feature. Figure S1 details screenshots of the Active^{+}me REMOTE app.

Onboarding, where participants were taught how to use all features of the Active^{+}me REMOTE app, was conducted by staff from Aseptika Ltd in a scheduled 60 min, in-person one-to-one session. The 60-min onboarding session was not included in the study app usage analysis. Onboarding was scheduled to take place as soon as possible after the PR assessment, ideally before the first scheduled supervised session.

Hybrid-PR participants undertaking Centre-PR could use the app to supplement their first eight supervised sessions, after which, they were asked if they would like to replace their final eight supervised sessions with the app only (Digital-PR). Reminder messages were delivered through the app daily, throughout the 8-week period of PR. PR clinicians encouraged all Hybrid-PR participants to use the app to facilitate, record and support any self-supervised exercise training. A dedicated support line available to all participants, offering one-on-one app support (including technical or general app usage enquires), was provided by Aseptika Ltd.

Propensity-matched comparator group

A comparator group (Control-PR) was recruited retrospectively from 633 participants assessed for PR at the same service in the previous 12 months. These participants were also offered Video-PR or Home-PR if they declined Centre-PR. They were propensity score matched 1:1 [15] with the intervention (Hybrid-PR) group, according to baseline characteristics, accounting for age, primary diagnosis (COPD or non-COPD), sex, mode of PR delivery (Centre-, Video- or Home-PR), index of multiple deprivation decile (as a socioeconomic measure) [16] and exercise capacity (measured by the incremental shuttle walk test [17]. A planned analysis of process outcomes between groups including PR completion, staff time and number of supervised sessions was conducted. The study was not powered to derive statistical improvement in clinical outcomes with Hybrid-PR compared with Control-PR.

Outcome measures

The primary outcome measure was assessment of the feasibility of a future randomised controlled trial based on recruitment and participant withdrawal rates, success of propensity matching, availability of data, patient and staff acceptability through quantitative and qualitative methodology, and safety (table 1).

Secondary outcomes were fidelity of Hybrid-PR (including app activation, adherence and usage), descriptive changes in core clinical outcomes following Hybrid-PR compared to a propensity-matched cohort (Control-PR) (table 1).

Sample size

As this was a feasibility study where the primary outcome included estimation of recruitment and retention rate for a future randomised controlled trial, a formal sample size was not calculated. The recruitment period for Hybrid-PR was pre-determined at 16 weeks with participant recruitment limited to a maximum of 100 to meet the funding body's timelines and resources.

TABLE 1 Primary (feasibility outcomes)

Feasibility measure	Criteria
Recruitment rates	Ability to recruit as planned
Reason for nonparticipation	Reasons for not participating
Study withdrawal rates	Number of participants withdrawn from study
Fidelity of Hybrid-PR	% successfully onboarded, timing of onboarding, App activation and usage
Success of propensity matching	Similarity of baseline characteristics between groups and difference between groups in nonclinical outcomes
Availability of data for larger definitive trial	% of missing data from routine and research data
Patient acceptability of Hybrid-PR	Nested semi-structured qualitative interviews with 15 participants
Staff experience of Hybrid-PR	In-person focus group
Safety	Number and consequences of adverse events and serious adverse events; comparison with propensity matched comparator group

PR: pulmonary rehabilitation.

Statistical analysis

Quantitative outcomes were reported using descriptive statistics. Data were assessed for normality by inspection of histograms. The comparator control group was determined using propensity matching using a logistic regression model; predicted values were calculated using probabilities and matched using the nearest-neighbour method [11]. Balance between propensity matching was assessed using pseudo R^2 [18]. Within-group changes in clinical outcomes were analysed using a paired t-test. Between group differences were performed using an unpaired t-test or a chi-squared test. A two-tailed level of $p<0.05$ was considered statistically significant. Statistical analyses were performed by SPSS v29.0.1.0 (IBM, Inc., Chicago, IL).

Results

Baseline characteristics

Baseline characteristics of the Hybrid-PR group is presented in table 2.

Feasibility

Recruitment and retention

A study flow chart is presented in figure 1. Of 232 people referred for PR during the study, 178 (77%) were eligible. 12 participants requested loan of a pre-paid smart phone to take part in the study. A total of 69 participants were recruited to the study (39% of eligible). Of those recruited, 60 (87%) attended

TABLE 2 Baseline characteristics of Hybrid-pulmonary rehabilitation (PR) cohort and propensity matched Control-PR cohort

Variable	Hybrid-PR (n=69)	Control-PR (n=69)
Age (years)[#]	68.0±11.8	68.8±11.7
Sex (male:female)[#]	32:37	37:32
IMD decile (1–10)[#]	5.9±2.5	6.0±2.4
ISW (m)[#]	247.2±169.5	277.7±215.8
MRC dyspnoea scale[#]	3.0 (2.5–4.0)	3.0 (2.5–4.0)
Number of hospitalisations in past year	0.0 (0.0–1.0)	0.0 (0.0–1.0)
Disease (% group)[#]		
COPD	65	62
Interstitial lung disease	10	17
Asthma	13	10
Bronchiectasis	7	4
Obstructive sleep apnoea	4	1
Long COVID	1	3
Breathing pattern disorder	–	1
Exertional shortness of breath	–	1
Video-assisted thoracotomy	–	1
BMI ($kg \cdot m^{-2}$)	30.1±6.7	27.9±7.4
CRQ score – dyspnoea[¶]	12.7±5.5	15.1±6.8
CRQ score – fatigue	12.8±4.8	13.3±5.2
CRQ score – emotions	30.9±9.9	30.0±9.3
CRQ score – mastery	18.5±5.9	17.7±5.9
CRQ score – total	74.8±20.9	75.6±23.1
CAT score	22.13±8.05	22.0±8.0
EQ-5D-5L score – utility	0.67±0.26	–
EQ-5D-5L score – visual analogue scale	63.2±18.1	–
1RM (kg)	34.4±18.6	35.0±18.3
SPPB score	9.2±2.5	9.7±2.8
5STS time (s)	14.7±10.3	12.7±7.5
4 m gait speed ($m \cdot s^{-1}$)	0.92±0.21	0.94±0.25
LINQ score	9.3±4.5	8.6±4.4
HADS-A score	7.6±4.9	8.0±4.9
HADS-D score	6.9±4.0	6.8±3.6

Data presented as mean±SD, median (interquartile range (IQR)), percentage (%), or ratio. 1RM: bilateral knee extension one repetition maximum; 5STS: five repetition sit to stand; BMI: body mass index; CAT: COPD Assessment Tool; CRQ: chronic respiratory questionnaire; HADS: Hospital Anxiety and Depression Scale; EQ-5D-5L: EuroQol–Five dimensions–Five levels; IMD: index of multiple deprivation; ISW: incremental shuttle walk test; LINQ: Lung Information Needs Questionnaire; MRC: Medical Research Council; SPPB: short physical performance battery. [#]: Propensity matched variable. [¶]: Significant difference between groups.

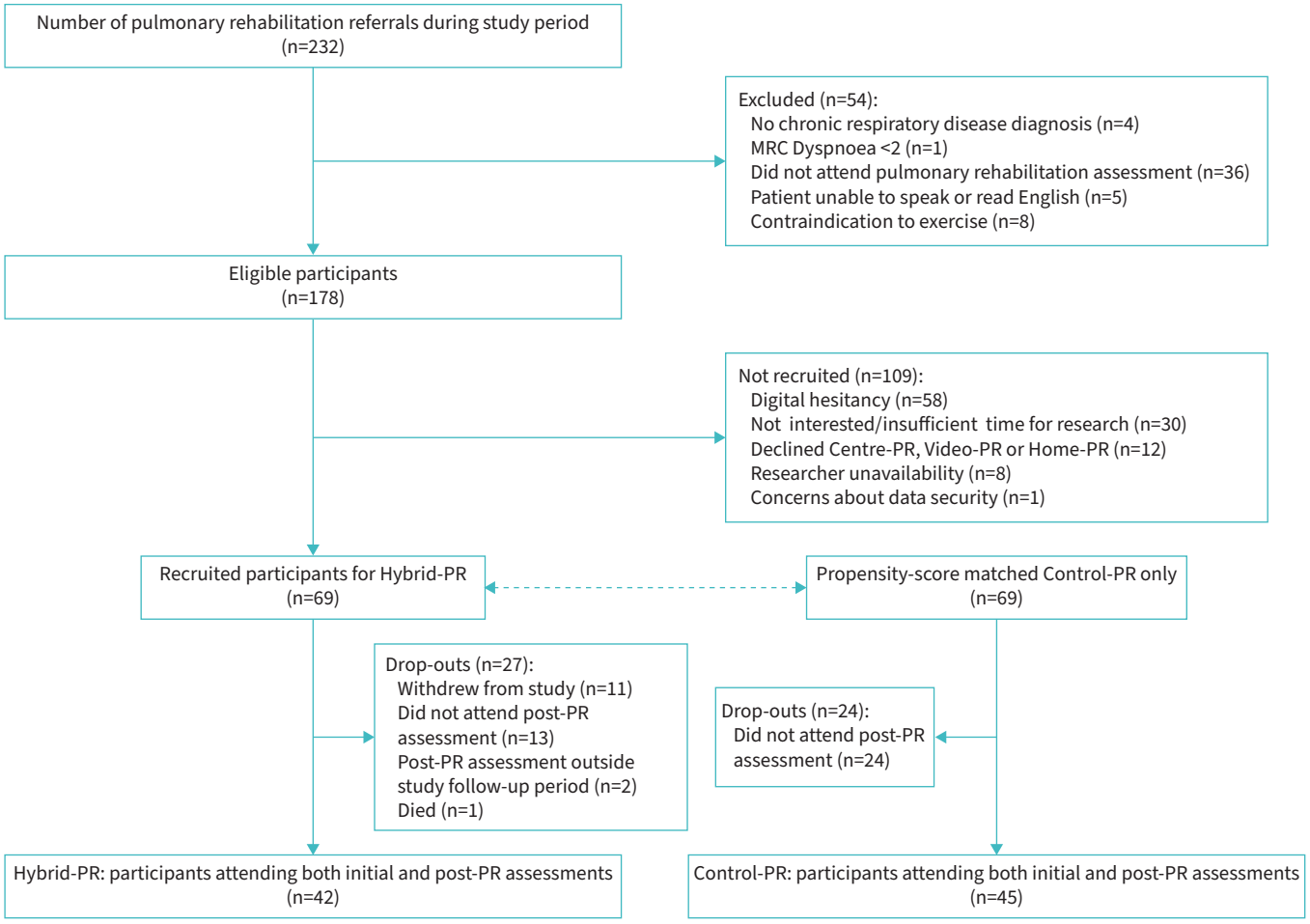

FIGURE 1 Study flow chart.

Centre-PR, seven (10%) Video-PR and two (3%) Home-PR. 42 participants (61%) attended post-PR assessment.

Safety

There were eight serious adverse events (requiring hospitalisation, one resulting in death) and 38 adverse events in Hybrid-PR. None of the adverse events (serious or otherwise) were attributable to the intervention.

Fidelity of hybrid-PR (onboarding, app activation and usage)

Onboarding

60 participants (87%) completed onboarding. Median (interquartile range) time to onboard from baseline assessment was 4.5 (0–11.0) days with 33 onboarded prior to starting PR and 27 after. For those onboarded after starting PR, median time was 8.0 days (2.0–14.0) after starting PR. The reasons for failure to onboard were withdrawal from study before onboarding (n=4), not attending the onboarding appointment (n=3) and illness preventing onboarding (n=2).

Digital-PR app engagement and usage

59 participants (86%) activated the app at least once during the study period.

Table 3 outlines overall app engagement (% of days used over 8 weeks) and broken down into component activities. App engagement was defined as opening the app and engaging in an app-related activity.

Of note, there was poor engagement with the exercise videos, with only eight participants (12%) ever accessing the pre-recorded exercise video function. Table S1 details individual participant engagement with

TABLE 3 Per patient app usage over the intervention period (56 days)

	All (n=69)	Centre- PR (n=60)	Video-PR (n=7)	Home-PR (n=2)
App engagement (% of days)	44.20±37.04	40.31±35.63	80.61±33.43	36.60±36.62
Number of exercise videos accessed	0.23±0.91	0.08±0.33	0.5±0.70	1.43±2.5
Number of education sessions read	4.74±10.37	3.45±7.95	17.14±19.84	0.50±0.71
Number of exercise sessions logged	8.58±15.98	8.84±14.29	21.0±30.10	1.5±0.71

Data presented as mean±SD. App engagement defined as reading an educational session, watching a pre-recorded exercise video, activating the step counter, manually logging an exercise session, logging of symptoms or recording physiological data (*e.g.* oxygen saturations).

exercise videos. Participants undertaking Video-PR engaged in a mean of 17.1 online educational sessions compared to 3.45 and 0.5 online educational sessions in the Centre-PR and Home-PR participants, respectively (table 3).

Only 35% of the intervention group logged into the app at least once per week during every week of the 8-week PR period. Figure 2a details the percentage of the intervention group who logged in at least once each week and figure 2b details the mean number of log-ins per patient per week.

Figure S2 details the percentage of participants that manually logged physical activity, activated the step counter, logged S_{pO_2} readings or entered symptoms at least once per week over the 8-week intervention period. Table S2 shows a detailed breakdown of engagement with the app (physical activity logged in minutes, number of steps logged and frequency of symptoms logged).

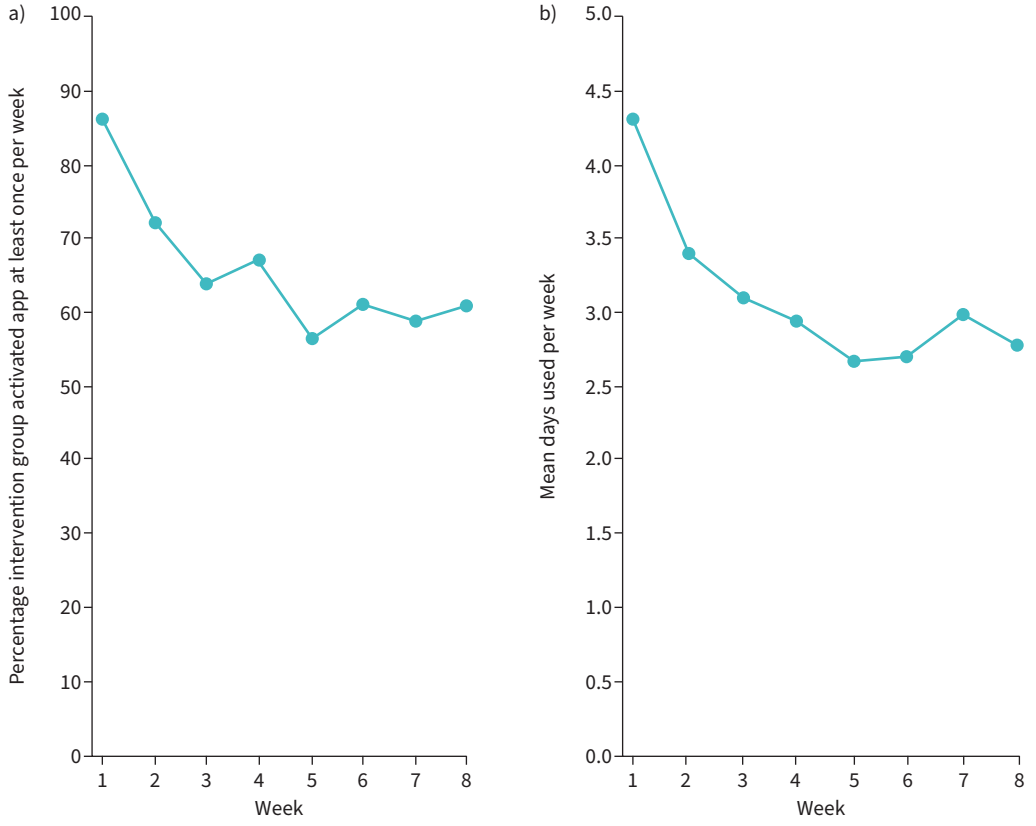

FIGURE 2 App logins. a) Percentage of the intervention group who logged in at least once each week and b) mean number of log-ins per patient per week.

Patient transition to Digital-PR only

During Hybrid-PR, only one participant continued their PR programme using Digital-PR only; of note, they only accessed the app three times over this 4-week period. The main reasons for declining Digital-PR only were not attending eight Centre-PR sessions (n=35), enjoying or finding Centre-PR motivating (n=22) and unable to use the app/Digital-PR independently (n=11).

Propensity matching and nonclinical outcomes between groups

Baseline characteristics of the propensity-matched Control-PR group is presented in table 2. The Hybrid-PR and Control-PR groups were well matched for all propensity-score variables (pseudo R^2=0.019).

PR completion, supervised sessions attended and staff time

There was no significant difference (p=0.605) in PR completion rates (*i.e.* those participants that attended both initial and post-PR assessments) between the Hybrid-PR and Control-PR groups (n=42 and n=45 respectively) (figure 1), nor in the number of supervised sessions attended in the Hybrid-PR and Control-PR groups (mean±SD 8.7±4.8 and 8.3±5.2 per patient, respectively; p=0.660). There was no significant difference in staff time per patient in the Hybrid-PR group compared to Control-PR (mean±SD 1226.9±574.7 and 1121.7±629.6 min, respectively; p=0.307) (figure 1). For all clinical outcomes, there was little missing data other than for bilateral knee extension one repetition maximum and Lung Information Needs Questionnaire results (table S3).

Table 4 summarises changes in clinical outcomes in both groups.

Patient and staff acceptability

Detailed description of the participant interviews and staff focus groups will be described in a separate publication. In summary, healthcare professionals acknowledged the potential usefulness of Digital-PR as an adjunct to Centre- or Home-PR, and as a way of supporting maintenance following the end of supervised PR. However, they expressed concern about the limited flexibility to adapt/tailor the app according to patient demographic, as well as the potential time commitment associated with on-boarding and support. These were barriers to widespread service adoption. Among patients, low digital skills hindered their engagement with the app. Most of these patients described effort and frustration when using the app.

TABLE 4 Change in clinical outcomes

Variable	Baseline Hybrid-PR	Pre-post change Hybrid-PR group	Baseline Control-PR	Pre–post change Control-PR
ISW (m)	247.2±169.5	63.1 (40.2–86.0)	277.7±215.8	49.3 (33.8–64.8)
CRQ score – dyspnoea	12.7±5.5	7.0 (4.5–9.5)	15.1±6.8	4.2 (2.3–6.0)
CRQ score – fatigue	12.8±4.8	3.18 (1.7–4.6)	13.3±5.2	2.4 (1.1–3.6)
CRQ score – emotions	30.9±9.9	3.48 (1.2–5.7)	30.0±9.3	3.7 (1.7–5.7)
CRQ score – mastery	18.5±5.9	2.18 (0.9–3.4)	17.7±5.9	3.0 (1.5–4.5)
CRQ score – total	74.8±20.9	15.8 (10.1–21.5)	75.6±23.1	13.7 (8.8–18.5)
CAT score	22.1±8.1	−3.1 (−4.5– −1.6)	22.0±8.0	−2.9 (−4.5– −1.4)
MRC score	3.0 (2.5–4.0)	0.0 (−1.0–0.0)	3.0 (2.5–4.0)	−1.0 (−1.0–0.0)
EQ-5D-5L score – utility	0.67±0.26	0.04 (−0.0008–0.08)	–	–
EQ-5D-5L score – visual analogue scale	63.2±18.1	2.80 (−2.0–7.6)	–	–
1RM	34.1±18.6	6.95 (3.8–10.1)	35.0±18.3	8.0 (5.2–10.9)
SPPB score	9.2±2.5	0.73 (0.2–1.3)	9.7±2.8	0.9 (0.3–1.4)
5STS time (s)	14.7±10.3	−4.25 (−6.4– −2.1)	12.7±7.5	−3.3 (−5.9– −0.7)
4 m gait speed ($m \cdot s^{-1}$)	0.92±0.21	−0.02 (−0.03–0.07)	0.94±0.3	0.06 (0.02–0.1)
LINQ score	9.3±4.5	−3.88 (−5.4– −2.3)	8.6±4.4	−3.9 (−5.2– −2.7)
HADS-A score	7.6±4.9	−1.02 (−2.1–0.03)	8.0±4.9	−1.8 (−2.9– −0.8)
HADS-D score	6.9±4.0	−0.93 (−1.8– −0.06)	6.8±3.6	−1.3 (−2.2– −0.5)

Data presented as mean±SD, mean (95% confidence interval) or median (interquartile range). 1RM: bilateral knee extension one repetition maximum; 5STS: five repetition sit to stand; CAT: COPD Assessment Tool; CRQ: chronic respiratory questionnaire; EQ-5D-5L: EuroQol–Five dimensions–Five levels; HADS: Hospital Anxiety and Depression Scale; ISW: incremental shuttle walk test; LINQ: Lung Information Needs Questionnaire; MRC: Medical Research Council; SPPB: short physical performance battery.

Discussion

This study is the first real-world feasibility study evaluating a hybrid PR programme (Hybrid-PR); blending traditional outpatient centre-based PR with access to a smartphone application providing a digital web-based PR programme (Digital-PR).

Although recruitment rates in our study were reasonable, poor digital literacy is prevalent amongst people referred for PR [19, 20] and is a major barrier to participation in Digital-PR studies. Even after recruitment, a vast majority of participants eligible to transition to Digital-PR declined, with 66% expressing a strong preference for supervised, in-person Centre-PR, and 33% expressing they were unable to use the app/Digital-PR independently. Contrary to expectations, provision of Digital-PR as part of Hybrid-PR did not reduce demand for supervised PR sessions compared to the propensity-matched Control-PR group without access to Digital-PR.

There has been growing interest in developing Digital-PR models [1] as they have the potential to address some of the reported barriers to PR uptake and adherence (such as accessibility). Although the evidence for Digital-PR remains in its infancy, trials have largely demonstrated comparable short-term benefits to Centre-PR. Bourne *et al.* [7] compared the web-based myCOPD to Centre-PR, demonstrating noninferiority in exercise capacity and health-related quality of life improvements. Chaplin *et al.* [8] randomised COPD participants to the web-based SPACE for COPD or outpatient Centre-PR, demonstrating similar improvements in endurance shuttle walk and dyspnoea. However, there were methodological limitations common to both studies with the comparator arms for both trials falling short of what is considered good-quality Centre-PR [1]. In trial described by Bourne *et al.* [7], Centre-PR comprised exercise stations matched to those provided by myCOPD app; whilst in the study by Chaplin *et al.* [8], some participants were provided with only 4 weeks of supervised training. Frith *et al.* [14] evaluated using the Active^{+}me REMOTE App (as used in our study) to supplement remote CR during the COVID-19 pandemic when in-person services were suspended. Digital hesitancy was apparent during their study, even with a younger study cohort than ours (mean±SD age of 60.4±10.9 years *versus* 68.0±11.8 years); only 29.9% of patients agreed to use the app to supplement remote CR. The app was predominantly used for clinicians to communicate with patients, with little emphasis on use of the pre-recorded exercise sessions, education or logging of exercise. Whilst the authors report the app was acceptable, some patients were hesitant about using the exercise features and found some app features overwhelming [14].

Previous trial populations may not be representative of real-world patient pathways. In Bourne *et al.* [7], the trial excluded 45% of participants including those with more complex needs such as those with oxygen requirements, currently exacerbating, significant comorbidities and those with non-COPD diagnoses. Specific inclusion criteria included “access to the internet and the ability to operate a web platform”. The trial did not specify the number excluded as part of the screening process, but based on previous observational studies in the UK, it is likely to have been significant [7, 19, 21]. Chaplin *et al.* [8] invited 2646 participants to participate (which were pre-screened), excluding those “without access to the internet for more than 3 months, the ability to navigate around a variety of websites and regular use of email”, resulting in just 641 responses. 46% of these patients were not interested (no reasons indicated) and 38% were not eligible; of note, around half of the 38% of ineligible patients were excluded due to no internet access. A further consideration is that authors on both papers were directly involved in the development or marketing of the respective Digital-PR products.

Our study is distinct from these previous trials. First, the study was designed to test the feasibility of delivering a blended Hybrid-PR model (exploring how Digital-PR might be able to support Centre-PR) within a real-world setting, rather than testing whether Digital-PR is noninferior to Centre-PR in a highly selective trial population. Other “hybrid-PR” models have used digital technology only to either supplement remote PR models [9, 14] or as a shared decision aid to Centre-PR [10]. Second, unlike previous trials, we did not exclude those with poor digital literacy; indeed, we took an “all-comer” approach and carefully reported the reasons for non-recruitment. Our approach may explain the reasonable recruitment rates for our study (77% of screened patients were eligible, as none were excluded due to poor digital literacy or no internet access), but the low compliance with Hybrid-PR compared to previous studies [7, 8]; 12 participants in Hybrid-PR requested a loan of a pre-paid smartphone, potentially indicating low digital literacy skills. Additionally, 11 participants (only two of whom requested a pre-paid smartphone) reported they were unable to use the app/Digital-PR independently despite onboarding and the provision of individualised support *via* the app developer (Aseptika). In those who were recruited to Hybrid-PR, we described carefully the activation of the app and how it was used. Third, we took a mixed-methods approach which provides a better understanding of some of the barriers to (and potential

benefits of) Digital-PR models from patient and provider perspectives. Fourth, we explored a wide range of clinical outcomes, including some rarely reported in previous Digital-PR studies. These included lower limb strength, functional performance and patient knowledge [22], important outcomes given that lower limb resistance training and education are core components of PR [1]. Furthermore, we also used the EuroQol–5 Dimensions–5 Levels instrument [23] and estimated changes in utility index. This is widely used to estimate health benefits in terms of quality-adjusted life-years and is one of only a few measures recommended for use in cost-effectiveness analyses [24]. Finally, we conducted an independent evaluation; developers of the App were excluded from data analysis, interpretation or authorship.

Several aspects of the data highlight and corroborate previous reports of poor digital literacy within PR populations [19]. Although the COVID-19 pandemic accelerated the use of digital health, digital literacy of patients with chronic respiratory disease has not accelerated to the same extent [20]. We observed that digital hesitancy was the most important factor for nonrecruitment (figure 1), despite offering free internet-enabled smartphones and dedicated one-to-one onboarding sessions to support use of the app. Even in those recruited to Hybrid-PR, only 35% regularly activated the app during the 8-week PR period despite daily text reminders. Detailed analysis of app usage showed significant heterogeneity across patients, but a universal finding was poor uptake of the pre-recorded exercise videos, disappointing given that exercise training is a core component of PR.

Frustration with the technical aspects of Digital-PR and the positive impact of Centre-PR on motivation and enjoyment of PR sessions were important reasons for participants not switching from Hybrid-PR to Digital-PR only. Data suggest encouragement from staff and peer support act as a source of motivation for patients during PR [25]. Consequently, only one participant within the Hybrid-PR group voluntarily chose to replace some of their scheduled in-person-PR sessions with Digital-PR, but then rarely accessed the app during this time. This was an important finding within the context of this feasibility study and was contrary to our hypothesis that the additional costs of Digital-PR could be off-set with staff savings from the reduced demand for supervised PR sessions with a Hybrid-PR approach. This has implications for future trial designs; demonstrating cost-effectiveness of Hybrid-PR would need to show that such an approach is superior, rather than just noninferior, to current standard of care, given the likely additional costs. Our qualitative interviews, with participants and staff corroborated these points; participants self-reported low literacy skills and frustration with using the app. Staff were concerned about the potential time commitment associated with onboarding and support (which in turn would increase service pressures and potential costs). A detailed account of these interviews will be reported elsewhere.

Despite the overall limited use of Digital-PR within the intervention group, one positive finding (albeit in small numbers) was that those undergoing Video-PR were the most regular users of the app. From their choice of PR modality, we speculate that these participants were more digitally literate. Interestingly, the component of the app that was accessed most regularly by these participants was the education sessions. Further work is needed to compare the delivery of educational sessions during Video-PR and in-person Centre-PR as previous trials have largely focused on exercise capacity and health status measures [12, 22, 26].

There were several limitations to our study. First, this was a single-centre study and therefore the results may not be generalisable. In particular, Digital-PR may have been taken up more where there is a higher proportion of digitally literate patients, a greater number of patients with accessibility issues to local PR centres or where there are long waiting times. Second, our study was not randomised and standard of care PR was offered to all participants. Our bias is that this pragmatic approach might reduce the highly selective trial populations observed in previous randomised controlled trial [7, 8]. Third, we did not formally collect any cost data and therefore we cannot comment on the cost-effectiveness of Hybrid-PR. However, given that only one participant decided to eschew their Centre-PR sessions in favour of Digital-PR, it is likely Digital-PR would increase the costs of a Hybrid-PR model over Centre-PR. Finally, the study was designed as a short-term feasibility study and therefore there was no data on how Digital-PR was used after the formal 8 weeks of PR. We therefore cannot comment on whether Digital-PR has a role in maintaining the benefits of Centre-PR [27].

In summary, this study is the first to report a Hybrid-PR model, blending Digital-PR with other models of PR. Poor digital literacy, despite provision of equipment and personal support, is an important barrier to the uptake of and engagement with Digital-PR. Hybrid-PR was not associated with a reduction in scheduled supervised Centre-PR sessions and therefore this model is likely to be associated with additional costs compared with Centre-PR alone. This has implications for future trial designs and for health buyers when considering the implementation of Digital-PR into real-world pathways.

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