Original research

Using a smartphone application maintains physical activity following pulmonary rehabilitation in patients with COPD: a randomised controlled trial

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ABSTRACT

Background Evidence suggests that patients with COPD struggle to maintain improved physical activity (PA) after completing pulmonary rehabilitation (PR). Smartphone applications (apps) providing a comprehensive training programme have conferred healthy benefits. This study was conducted to determine whether regular usage of an app maintains PA following PR.

Methods Patients with stage II–IV COPD were enrolled in a 6-month trial following PR. After the screening period, participants were randomised into the Kaia COPD app group (intervention group (IG)) or the control group (CG). The primary outcome was PA (daily steps), measured using an activity tracker. Secondary outcomes included the COPD Assessment Test (CAT), the Chronic Respiratory Disease Questionnaire (CRQ) and the 1 min Sit-to-Stand Test (STST).

Results Sixty participants completed the study. The median steps from baseline to 6 months were significantly different between the groups, in favour of the IG (−105.3, IQR −1970.1 to 2105.8, vs CG −1173.0, IQR −3813.1 to −93.8; p=0.007). CAT was significantly decreased in the IG (15.1±8.6 vs 19.7±6.4, p=0.02), whereas the CRQ subdomains for dyspnoea (4.5±1.7 vs 3.7±1.3, p=0.033) and fatigue (4.5±1.4 vs 3.5±1.3, p=0.028) improved significantly in the IG. The STST at 6 months was not significant. Sleep duration and sleep efficiency showed no significant differences between the two groups at any time.

Conclusions A comprehensive program by using the Kaia app following PR maintained PA and improved symptoms in patients with COPD at 6 months. The app might be an important accessory tool for enhanced COPD care.

Trial registration number DRKS00017275.

Key messages

What is already known on this topic
► To date, no study has been able to demonstrate the benefits of eHealth in the postrehabilitation phase, especially in terms of maintaining physical activity (PA) in patients with COPD.

What this study adds
► Regular use of the contents of the smartphone application (app) Kaia COPD app not only maintained PA in patients with COPD after rehabilitation but also improved symptoms.

How this study might affect research, practice or policy
► Widespread use of eHealth has the potential to close the long-known gap in postrehabilitation.

INTRODUCTION

Pulmonary rehabilitation (PR) is defined as a multidisciplinary and comprehensive intervention based on a thorough patient assessment followed by patient-tailored therapies that include, but are not limited to, exercise training, education and behavioural changes designed to improve the physical and psychological condition of people with chronic respiratory disease and to promote long-term adherence to health-enhancing behaviours.[1] PR is considered an important modality for non-pharmacological management of COPD. Numerous trials have shown that participation in a PR programme improves health-related quality of life (HRQoL) and exercise capacity in patients with COPD.[2] However, it is often challenging for patients with COPD who have completed a PR programme to maintain physical activity (PA) and to integrate regular exercise training into their daily lives. Consequently, many patients with COPD fail to adhere to exercise training after completing PR and receive insufficient instructions to continue their exercise training at home.[3]

A systematic review and meta-analysis of single-group and randomised trials evaluating the effect of exercise training (not necessarily PR) on PA concluded that this intervention conferred a small but significant increase in this outcome.[4] Studies have highlighted the crucial importance of maintaining PA in COPD showing significantly higher survival rates correlated with increased PA.[5 6] Several studies confirmed that a sustainable increase in PA following PR in patients with COPD with declining levels of PA is inconsistent following structured PR programmes.[7 8]

Digital therapeutics to promote behavioural change in chronic conditions have recently emerged with a growing body of evidence supporting their use across many indications.[9] Of note, digital rehabilitation tools have been suggested as a means of increasing access to rehabilitation and structured exercise in different indications.[10] [11] Recent studies have investigated the effect of short-course digital interventions for PR in COPD, comparing them against face-to-face outpatient PR, which demonstrated comparable results in terms of HRQoL and exercise capacity as measured by the 6 min walk test.[12] Further pilot studies have suggested the potential of digital applications (app) to also improve HRQoL and to reduce hospital readmissions in patients with severe symptoms when compared with standard care.[13] Another pilot study suggested a moderate improvement in HRQoL in newly diagnosed COPD, regardless of disease severity.[14] The effect of mobile health (mHealth) app use on PA was also investigated in an early feasibility mixed-methods study, but the effect of app usage on PA was not detected.[15]

The Kaia COPD app is available as a digital solution for PR and consists of an exercise training programme, breathing exercises and an educational programme.[16] To the best of the authors' knowledge, no current evidence supports the use of digital health interventions following structured PR programme PA. We hypothesised that the use of this smartphone app would maintain PA in patients with COPD following PR.

METHODS
Participants and study centres
This trial was conducted as an international, bicentre, parallel-group randomised controlled trial (RCT). Study participants were in COPD Global Initiative for Obstructive Lung Disease (GOLD) stages II–IV who were randomised in a 1:1 ratio in parallel assignment to either the intervention group (IG), which was provided with the Kaia COPD app, or the control group (CG), which received standard care (accomplished by using a software randomiser, https://www.randomizer.org). Two centres specialised in inpatient PR for COPD (Schoen Klinik Berchtesgadener Land, Germany, and Zurich RehaCenter Clinic Wald, Switzerland) recruited participants. The trial was reported in line with the Consolidated Standards of Reporting Trials recommendations for the reporting of RCTs.[17]

The study was registered with the German Clinical Trials Register. A summary of the study protocol has been published.[18]

Objectives and outcomes
The primary objective was to assess the effectiveness of the newly developed COPD app as a maintenance programme after PR. The primary outcome was defined as a change in PA, measured in steps per day after 6 months. A commonly used activity tracker (POLAR A370 watch; Polar Electro Europe AG, Steinhausen, Switzerland) was used to measure the results of the primary endpoint. In a previous study, this activity tracker was also shown to be valid for daily life assessment of PA in patients with COPD.[19]

The secondary objectives were to evaluate the effects of the COPD app programme on functional exercise capacity (1 min Sit-to-Stand Test (STST)[20]), HRQoL and patient-reported health status (Chronic Respiratory Disease Questionnaire (CRQ)[21] and COPD Assessment Test (CAT)[22]), number of exacerbations (defined as an increase in symptoms and an increase in dosage of or a new prescription of systemic corticosteroids and/or antibiotics), and depression and anxiety symptoms (Hospital Anxiety and Depression Scale[23]). Furthermore, we aimed to investigate

patients' compliance, adherence and safety; to identify factors that facilitate the implementation of the programme in the patient's home setting; and to evaluate factors of the programme that are especially supportive of patient care. For additional information regarding materials and methods, see online supplemental material.

Intervention
The study intervention consisted of physical exercise training sessions conducted daily by the patient via the Kaia COPD app. The app is available as a digital solution for PR in German-speaking countries. This COPD app consisted of an exercise training programme, breathing exercises and an educational programme, and was developed by healthcare professionals and PR experts. In a feasibility study for the Kaia app, promising results were obtained from a 20-day intervention on the CAT and HRQoL in patients with severely symptomatic COPD.[16]

Regular contacts via telephone calls were made by a trained healthcare professional to assess and discuss compliance with the study intervention. Additionally, patients were contacted by phone if they did not meet the predefined minimal adherence criteria (exercising with the app at least 4 out of 7 days a week).

Individualised strength training programme
The exercise training programme provided by the COPD app consisted of various daily whole-body exercises of 15–20 min. Most exercises included compound movements to train large muscle groups and improve upper and lower body strength and mobility. Each exercise day began with a whole-body warm-up and finished with two to three stretching exercises. During the programme, the intensity of the exercises was progressively increased dynamically based on patient feedback recorded through the application at the end of each exercise session. All exercises were explained in exercise videos, which included detailed instructions to ensure proper performance, training amount and intensity. Completed training sessions were recorded by the application, and aggregated data about training intensity and frequency were provided to the site staff to assess compliance with the study intervention. Within the exercise training programme, frequency of workouts, as well as exercise duration and intensity, were initially determined using a self-test assessing baseline exercise capacity. All exercises were performed without the need for specialised exercise equipment. Furthermore, the app promoted overall PA (eg, walking). The number of steps per day was collected by the activity tracker and reported to the app, and goals for activity were set weekly, depending on the updated individual fitness level. Users were reminded of their activity goals via push notifications provided by the app. The CG also wore the activity tracker every day and used a smartphone for the assessments but had no access to the COPD app. The IG and CG received a leaflet to encourage an active lifestyle (German version of 'living well with COPD') as well as individual exercise recommendations, as part of their discharge instructions to reflect the established standard of care. At the 6-month assessment, participants who were allocated to the CG were offered to use the Kaia COPD app free of charge.

Sample size calculation and statistics
Sample size calculation was based on expected changes in the primary endpoint and the average step difference between the groups from week 1 to the 6-month follow-up. The minimal

clinically important difference in steps per day after PR is estimated between 350 and 1100 steps as measured with an activity tracker during an intervention.[24] Assuming an SD of the outcome variable of 2500 steps/day, an expected effect size of 2000 steps/day could be assumed for programmes combining PA counselling with PR to increase activity. According to a current meta-analysis,[25] to achieve 80% power and a significance level of 5% (one-sided), a sample size of 52 participants (26 participants in each group) was required. Assuming a drop-out rate of 50%, enrolment of up to 104 participants was expected. From our study group, two RCTs on outpatient training interventions were published in advance, each demonstrating high drop-out rates of 45% and 57%.[26 27] The sample calculation and the primary outcome analysis were based on a two-tailed unpaired t-test comparing changes from baseline between the two groups at the final visit at the end of the follow-up period.

Discrete variables are presented as absolute and relative numbers. For continuous variables, the Shapiro-Wilk test was performed to determine the normality of distribution. Depending on the results of the Shapiro-Wilk test, mean and SD or median with IQR were reported. For discrete variables, group comparisons were performed using χ^2 tests. Continuous variables were compared with either t-tests or Mann-Whitney U tests, according to the normal distribution assumption. Data are presented as boxplots or mean plots with error bars. A p value of 5% was determined as significant for all analyses. For the main analyses, we compared the CG with the IG using an intention-to-treat approach. The effect size for the Mann-Whitney U tests was calculated using rank–biserial correlation; for t-tests, Cohen's d was calculated. This study was designed as a superiority study, and analyses were performed using the R V.4.1.1.

RESULTS

Recruitment and baseline characteristics

Overall, 421 subjects were screened for eligibility. The trial was conducted from July 2019 to June 2021. Enrolment was terminated after the planned number of participants completed the study (n=52). Figure 1 shows the protocol for screening, randomisation and follow-up. Table 1 shows the baseline demographics of the 67 randomised patients. The 67 participants with COPD had a mean age of 64±8 years and, according to the pulmonary
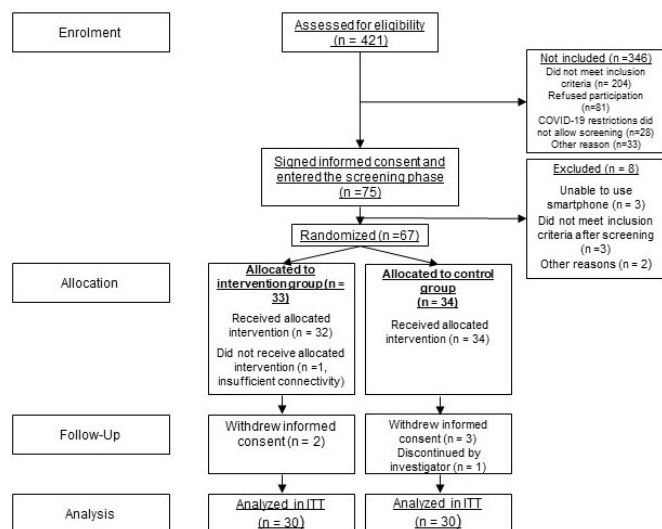

Figure 1 Consolidated Standards of Reporting Trials diagram. ITT, intention to treat.

Table 1 Demographic characteristics of the study population

Characteristics	Overall n=67	IG n=33	CG n=34
Age (years), mean (SD)	64.3 (7.7)	66.1 (6.8)	62.7 (8.2)
Sex (female), n (%)	33 (49.3)	16 (48.5)	17 (50.0)
BMI (kg/m²), mean (SD)	24.4 (5.1)	25.0 (4.7)	23.8 (5.6)
Current smoker, n (%)	8 (11.9)	3 (9.1)	5 (14.7)
Smoking in the past, n (%)	58 (86.6)	30 (90.9)	28 (82.4)
Never smoker, n (%)	1 (1.5)	0 (0.0)	1 (2.9)
Exacerbation in the last 12 months, n (%)	53 (79.1)	29 (87.9)	24 (70.6)
Number of exacerbations treated as outpatient in the past 12 months, mean (SD)	1.19 (1.14)	1.19 (1.33)	1.19 (0.87)
Number of exacerbations treated as inpatient in the past 12 months, mean (SD)	1.08 (1.23)	1.21 (1.50)	0.91 (0.79)
Long-term oxygen therapy, n (%)	40 (59.7)	18 (54.5)	22 (64.7)
FEV$_1$ (L) (mean (SD))	1.27 (0.50)	1.31 (0.53)	1.23 (0.46)
FEV$_1$% predicted (mean (SD))	44.0 (16.2)	45.5 (14.5)	42.6 (17.8)
FEV$_1$% FVC, mean (SD)	0.52 (0.14)	0.54 (0.14)	0.50 (0.15)
FVC% predicted, mean (SD)	64.8 (18.4)	63.9 (17.9)	65.7 (19.2)
CAT (points), mean (SD)	16.3 (7.09)	16.5 (7.2)	16.0 (7.1)
GOLD stage II, n (%)	20 (29.9)	10 (30.3)	10 (29.4)
GOLD stage III, n (%)	29 (43.3)	17 (51.5)	12 (35.3)
GOLD stage IV, n (%)	18 (26.9)	6 (18.2)	12 (35.3)

BMI, body mass index; CAT, COPD Assessment Test; CG, control group; FEV$_1$, forced expiratory volume in 1 s ; FVC, forced vital capacity; GOLD, Global Initiative for Obstructive Lung Disease; IG, intervention group;

function testing, severe airflow obstruction with a mean FEV$_1$% predicted of 44%±16%. Comorbidities are illustrated in table 2, showing no group differences according to distribution.

Primary outcome

The main analysis showed a significant difference in the change in median steps from baseline to 6 months between the groups (IG −105.9, IQR −1970.1 to 2105.8, vs CG −1173.0, IQR −3813.1 to −93.8 steps per day; p=0.007) (figure 2). The effect size was 0.402 (IQR 0.131–0.617).

The median number of daily steps at 6 months measured as an average value over 7 days was significantly higher in the IG (median steps and IQRs in the IG 5016.3 (2920.3–10 206.5)

Table 2 Comorbidities of the study population

Comorbidities	Overall n=67	IG n=33	CG n=34
Cardiac comorbidity, n (%)	39 (58.2)	20 (60.6)	19 (55.9)
Neurological comorbidity, n (%)	9 (13.4)	6 (18.2)	3 (8.8)
Metabolic comorbidity, n (%)	18 (27.3)	11 (33.3)	7 (21.2)
Musculoskeletal comorbidity, n (%)	28 (41.8)	17 (51.5)	11 (32.4)
Psychiatric comorbidity, n (%)	16 (23.9)	8 (24.2)	8 (23.5)
Other comorbidities, n (%)	26 (38.8)	17 (51.5)	9 (26.5)
History of lung surgery, n (%)	3 (4.5)	1 (3.0)	2 (5.9)

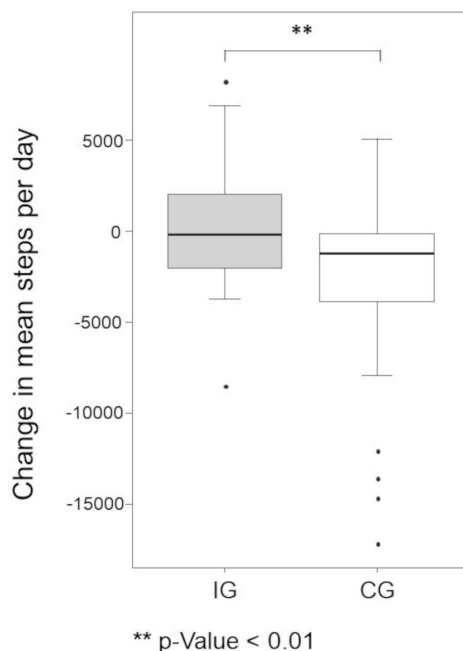CG, control group; IG, intervention group.

Figure 2 Changes in steps per day from baseline to 6 months. P value was obtained from the Mann-Whitney U test. CG, control group; IG, intervention group. **P<0.01.

vs 3105.1 (606.4–4372.0), p=0.014) than in the CG (figure 3). The effect size was 0.370 (IQR 0.095–0.593).

At baseline and 3 months, the differences were not significant between the groups (baseline, IG 6361.4 (IQR 3401.2–8304.3) vs CG 5052.21 (IQR 3531.9–8999.1) steps per day, p=0.760; effect size, 0.024 (IQR −0.264 to 0.309); 3 months, IG 4661.1 (IQR 2538.4–7829.0) vs CG 3728.0 (IQR 1889.3–5773.4) steps per day, p=0.199; effect size, 0.168 (IQR −0.125 to 0.433) (figure 3).

Secondary outcomes
COPD Assessment Test
CAT scores decreased from baseline to 6 months in the IG (−1.4 point mean difference) but increased in the CG by 3.7 points (p=0.02) (figure 4 and table 3).

Chronic Respiratory Disease Questionnaire
Significant differences were found between the IG and CG for the CRQ domains of dyspnoea and fatigue. The domains of emotional function and mastery, as well as the CRQ total score, did not show significant differences between groups (table 3).

Hospital Anxiety and Depression Scale
While Hospital Anxiety and Depression Scale–Depression Subscale (HADS-D) did not change significantly over the study period for the IG, the scores significantly increased for the CG (IG 4.20 (±2.95) vs CG 6.55 (±5.08), p=0.033) (figure 5). Group differences for the Hospital Anxiety and Depression Scale–Anxiety Subscale (HADS-A) and the total scores were not significant at 6 months (table 3).

Sit-to-Stand Test
At baseline, no significant difference in the number of STST repetitions was observed. After 3 months, participants in the IG performed a significantly higher number of repetitions, and after 6 months, no significant difference was noted in the number of STST repetitions (figure 6 and table 3).

Sleep parameters
Regarding sleep duration and sleep efficiency, no differences were found for both the CG and IG at any time (table 3).

App usage and adherence
The app usage for the IG is reported in line with adherence to definitions previously reported and listed in table 4.[14] A prespecified optimal usage rate of four different types of content, on four different days per week, was achieved by 36% of the participants. Using the prespecified adherence definition (use of the application at least four times a week for at least 70% of the weeks during the study), 13 participants (43%) in the IG complied fully with the app usage suggestions ('frequent app user'). As a sensitivity analysis, we reanalysed this subgroup of patients and found an even greater difference when compared with controls regarding the primary outcome (change in steps from baseline in the IG 1092.1 (−1036.3 to 2317.9) and in the CG −1173.0 (−3813.1 to −93.8), p=0.006). The results of the subgroup frequent app user are provided in online supplemental
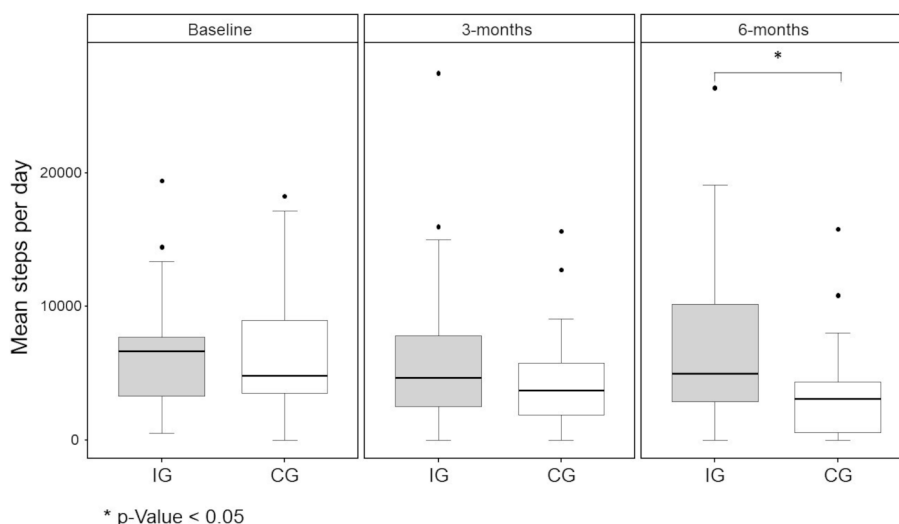

Figure 3 Steps per day at baseline and 3 and 6 months for the IG and the CG. P value obtained from the Mann-Whitney U test. CG, control group; IG, intervention group. *P<0.05.
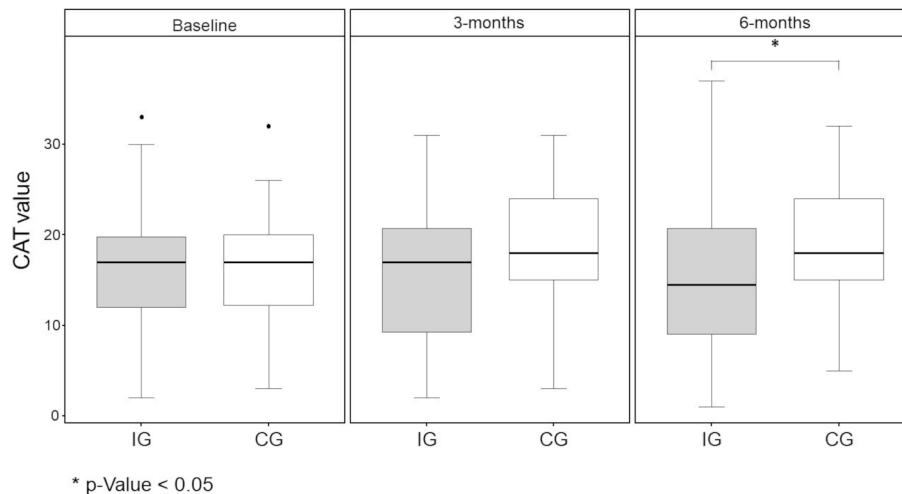
Figure 4 Results of the CAT for the IG and the CG. P value was obtained from the t-test. CAT, COPD Assessment Test; CG, control group; IG, intervention group. *P<0.05.

table S7). A visual representation of the participants' app usage is shown in figure 7.

Of the 30 participants, 29 (96.6%) completed the study, indicating that they were satisfied with the study app after using it. Ten (34.5%) participants rated it as 'okay', and 18 (62.1 %) rated it as 'very satisfactory'. All participants would recommend the app to other patients with COPD. There were no differences in safety endpoints. More detailed information regarding safety endpoints is provided in the online supplemental material.

DISCUSSION

The study investigated the effects of a digital-based post-PR programme provided via a smartphone app to maintain the positive results of PR as long as possible and to encourage patients to adopt a more active lifestyle. The results demonstrate that the maintenance of PA and a significant increase in HRQoL, up to 6 months after completing PR, were possible by using a mobile app for self-management of COPD. To our knowledge, this study is the first RCT to demonstrate the maintenance of PA after inpatient PR using a digital structured programme. In addition, differences in favour of the IG could be found in all observed endpoints of the study (except HADS-A) after 6 months, exceeding the minimal clinically important differences (online supplemental material). These positive app results are particularly impressive because the CG received the usual post-rehabilitation recommendations rather than no intervention. In addition to the application providing potential benefit of maintenance after participating in PR, it may provide benefit of increasing the uptake of digital delivery of PR overall.

PR has been demonstrated to significantly and reliably improve HRQoL and exercise capacity. However, the long-term effects on PA are moderate. Given its resource-intensive and costly nature, consolidation and maintenance of PR-induced benefits, especially in maintaining PA, remain a challenge across modes of delivery and healthcare systems. Structured exercise programmes aimed to improve the maintenance of benefits after PR showed mixed results when assessing exercise tolerance, HRQoL and PA.[28]

Additionally, the findings of the current study are of relevance because PA is an important outcome. Previous studies on this topic have shown ambivalent results, and most studies have focused on physical performance as the primary endpoint.[7 8] Since a higher exercise capacity does not necessarily lead to higher PA,[7 29] it is

of particular interest to evaluate the effects of a postrehabilitation programme on PA. Physical inactivity is a potential modifiable risk factor and should be clinically assessed as a vital sign of a patients' general physical condition prior to any exercise-based intervention.[30]

In this study, training on the use of the study equipment occurred during rehabilitation (four sessions, each of 20 min duration). When reduced to pure training with the app, the effort would be significantly lower, and a cost-effective and feasible application would be conceivable in the outpatient area. However, the extent to which a reduction in training times has an influence on adherence to the training app cannot be estimated.

Barriers to referral, uptake and completion of PR are well documented and linked with organisational, practitioner and patient-related factors.[31] However, the extent to which the use of a training app can close a gap here must certainly be evaluated in further studies. Findings from studies of maintenance programmes following PR are heterogeneous, especially regarding supervision frequency. A recently published Cochrane review including 21 studies with 1799 patients with COPD suggested that supervised maintenance programmes for patients with COPD after PR may improve HRQoL and could possibly improve exercise capacity at 6–12 months. The strength of the evidence was assessed as limited. The authors concluded that the optimal frequency of supervision and mode for supervised maintenance programmes are still unclear.[32] However, these studies also predominantly examined only the effects on the participants' physical performance and not the consequences in terms of PA. Interestingly, no significant changes between CG and IG were seen in the 3-month assessment. We suppose this to be the usual duration that PR effects are measurable. By the extended observation period of 6 months, significant differences between the groups could be seen. Our results confirm the experience of the ATS guidelines, stating that the benefits of PR in the absence of any maintenance strategy appeared to diminish over 6–12 months.[3] Another study tried to demonstrate the effects of an mHealth intervention to improve or maintain PA in patients with COPD after PR. However, no differences were observed in PA, functional exercise capacity, HRQoL outcomes or body mass index in patients with COPD using a consumer smartphone-based mHealth intervention.[33] The discrepancies between outcomes of the previous study and the current study might be caused by the different settings, as patients in the previous study were enrolled

Chronic obstructive pulmonary disease

Table 3 Results of secondary endpoints for the IG and CG

	Baseline				3 months				6 months			
	IG	CG	P value	Effect size (95% CI)	IG	CG	P value	Effect size (95% CI)	IG	CG	P value	Effect size (95% CI)
CAT points	16.53 (7.15)	16.00 (7.12)	0.773	0.075 (−0.432 to 0.581)	15.53 (8.26)	18.70 (6.71)	0.109	−0.421 (−0.931 to 0.093)	15.13 (8.58)	19.72 (6.42)	0.024	−0.605 (−1.124 to to 0.080)
STST repetitions	19.07 (5.77)	16.87 (7.07)	0.196	0.341 (0.175 to 0.853)	22.87 (8.00)	16.83 (7.64)	0.004	0.771 (0.243 to 1.293)	22.66 (7.23)	19.45 (9.09)	0.143	0.390 (−0.131 to 0.908)
CRQ domains												
Dyspnoea points	4.54 (1.45)	4.48 (1.19)	0.881	0.039 (−0.467 to 0.545)	4.51 (1.68)	3.96 (1.40)	0.170	0.359 (−0.153 to 0.868)	4.54 (1.65)	3.69 (1.31)	0.033	0.570 (0.047 to 1.089)
Fatigue points	4.60 (1.22)	4.68 (1.31)	0.820	−0.059 (−0.565 to 0.447)	4.31 (1.36)	3.74 (1.13)	0.085	0.453 (−0.062 to 0.963)	4.50 (1.28)	3.72 (1.36)	0.028	0.586 (0.062 to 1.105)
Emotional function points	5.40 (1.07)	5.14 (0.97)	0.325	0.256 (−0.253 to 0.763)	4.90 (1.31)	4.41 (1.32)	0.161	0.367 (−0.145 to 0.875)	4.92 (1.27)	4.54 (1.40)	0.283	0.282 (−0.232 to 0.794)
Mastery points	5.27 (1.23)	4.97 (1.27)	0.369	0.234 (−0.275 to 0.740)	5.18 (1.44)	4.63 (1.64)	0.180	0.351 (−0.161 to 0.859)	5.08 (1.50)	4.48 (1.51)	0.131	0.399 (−0.118 to 0.913)
Total CRQ points	4.95 (1.07)	4.82 (0.97)	0.618	0.129 (−0.378 to 0.636)	4.72 (1.31)	4.19 (1.18)	0.102	0.429 (0.085 to 0.940)	4.76 (1.30)	4.11 (1.26)	0.056	0.508 (−0.013 to 1.024)
Feeling thermometer degrees	61.57 (19)	61.57 (17)	1.000	0.000 (−0.506 to 0.506)	65.0 (20)	63.50 (20)	0.772	0.075 (−0.431 to 0.581)	66.43 (18)	58.93 (21)	0.147	0.383 (−0.134 to 0.896)
HADS-A points	4.10 (3.33)	4.10 (3.50)	1.000	0.000 (−0.506 to 0.506)	4.60 (3.74)	6.10 (4.16)	0.147	−0.380 (−0.889 to 0.133]	4.43 (3.50)	5.34 (4.19)	0.368	−0.236 (−0.748 to 0.277)
HADS-D points	4.23 (2.90)	4.23 (3.69)	1.000	0.000 (−0.506 to 0.506)	4.50 (2.74)	6.03 (4.41)	0.111	−0.418 (−0.928 to 0.095)	4.20 (2.95)	6.55 (5.08)	0.033	−0.569 (−1.087 to −0.046)
HADS total points	8.33 (5.60)	8.33 (6.47)	1.000	0.000 (−0.506 to 0.506)	8.33 (5.60)	8.33 (6.47)	1.000	0.000 [−0.506 to 0.506)	8.33 (5.60)	8.33 (6.47)	1.000	0.000 (−0.506 to 0.506)
Duration of sleep (hours)	7.61 (1.36)	7.73 (1.08)	0.703	−0.102 (0.621 to 0.418)	7.32 (1.28)	7.49 (1.89)	0.704	−0.105 (−0.644 to 0.434)	7.60 (1.31)	7.13 (1.69)	0.294	0.311 (−0.269 to 0.888)
Sleep efficiency (%)	91.71 (3.20)	90.84 (3.33)	0.321	0.265 (−0.257 to 0.786)	92.39 (2.37)	90.97 (2.73)	0.048	0.555 (0.004 to 1.102)	91.95 (2.28)	90.75 (2.93)	0.120	0.465 (−0.120 to 1.046)

Data are presented as mean and SD, and all p values were obtained from the t-tests.

CAT, COPD Assessment Test; CG, control group; CRQ, Chronic Respiratory Disease Questionnaire; HADS, Hospital Anxiety and Depression Scale; HADS-A, Hospital Anxiety and Depression Scale—Anxiety Subscale; HADS-D, Hospital Anxiety and Depression Scale—Depression Subscale; IG, intervention group; STST, Sit-to-Stand Test.
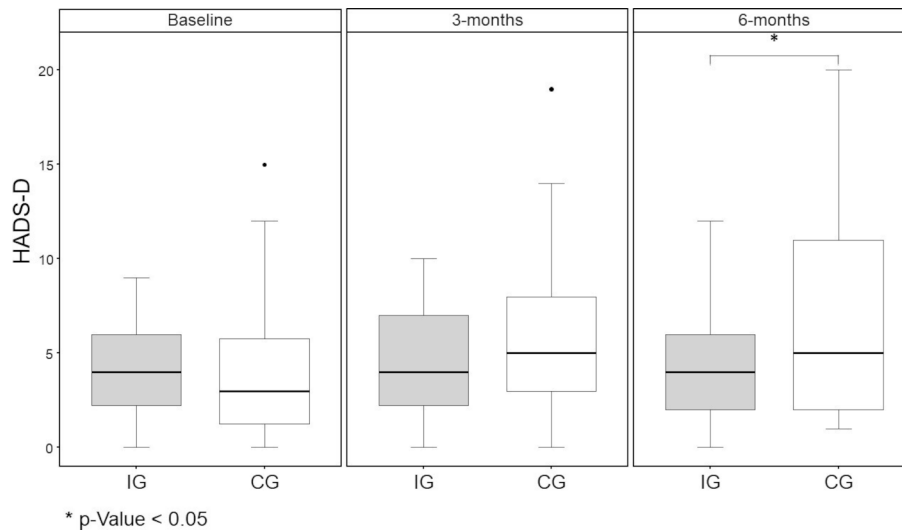
Figure 5 Results of the HADS-D for the IG and the CG. P value was obtained from the t-test. CG, control group; HADS-D, Hospital Anxiety and Depression Scale–Depression Subscale; IG, intervention group. *P<0.05.

until half a year after outpatient PR, and the different inclusion and exclusion criteria. In addition, differences between study interventions might have played a role.

Other disease-relevant outcomes such as the CAT, HRQoL measured by the dyspnoea and fatigue domains of the CRQ, and data on the mood of the patients assessed with the HADS-D showed a significant improvement in the IG compared with CG. Regarding the STST, a clinically and statistically significant difference was observed at 3 months, while no significant difference was noted at 6 months, which may be caused by the fact that the study was not sufficiently powered to detect such a change in the STST. These findings are in line with the effects observed in a retrospective pilot study of the same application, showing at least a significant improvement in the CAT score and the identical CRQ domains from baseline to the end of the observational period.[16] Our results support the findings of North *et al*, who had previously reported non-inferiority of a mHealth intervention to outpatient face-to-face PR on changes in functional exercise capacity and HrQoL in patients with COPD meeting referral criteria to PR.[13] In a recent study among patients with severe COPD, telerehabilitation (delivered though providers

instead of an app) also yielded equal results to face-to-face PR.[34] Of note, all participants in our study were included following a comprehensive rehabilitation, assuming that the patients were in their best possible condition with little potential for further improvements.

Another pilot study investigated the same intervention as Crooks *et al* in inpatients with COPD following an exacerbation and found clinically relevant effects on HRQoL and the incidence of exacerbations.[14] This study also reported an effect of a digital health intervention on PA, HRQoL and functional exercise capacity. The findings suggest that inpatient populations either are especially prone to profit from these interventions or reflect the well-documented effect of PR following exacerbations, as the majority of the participants of this study also had a history of a recent exacerbation.[35]

Notably, no significant difference was found between the groups with respect to the number of recorded exacerbations or adverse events (AEs). The intervention had a positive safety profile with a comparable incidence and distribution of AEs across the groups. These results are in line with the findings of the aforementioned Cochrane review showing that supervised
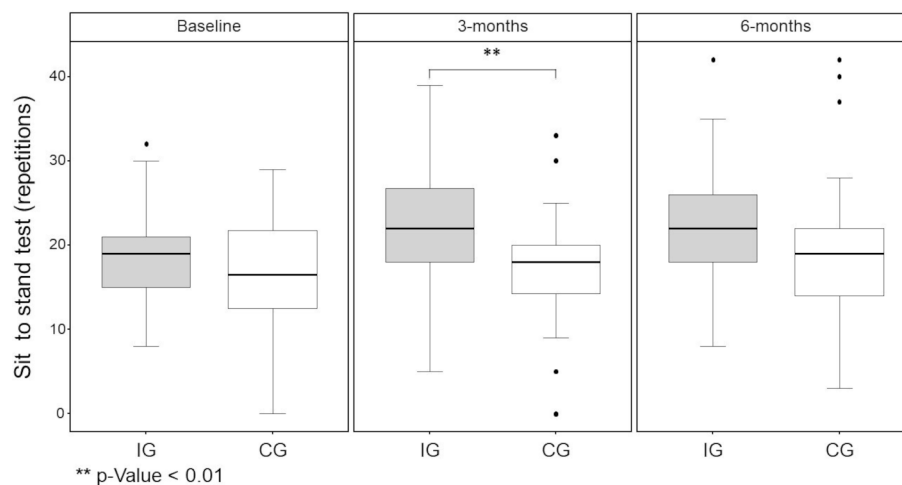

Figure 6 Results of the 1 min Sit-to-Stand Test for the IG and the CG. P value was obtained from the t-test. CG, control group; IG, intervention group. **P<0.01.

Table 4 Usage of the COPD app in the intervention group

	n (%)
Total use definitions	
Activating the app and at least one activity	29 (97)
Training on the app on at least 30 days	26 (87)
Training on the app on at least 60 days	24 (80)
Training on the app on at least 90 days	20 (67)
Training on the app on at least 120 days	13 (43)
Sustained use definitions	
An activity in the app in at least 50% of trial weeks (%)	79
An activity in the app in at least 75% of trial weeks (%)	61
Number of active days in the final week of the study (SD)	3.51 (2.71)

app, smartphone application.

maintenance programmes for patients with COPD after PR are not associated with increased AEs.[33]

However, it is still unknown which patients, in terms of disease progression or demographic properties, benefit the most from digital health apps for PR. Another recent pilot study investigated the use of an mHealth app in a collective of newly diagnosed, mild and moderately affected patients with COPD, but observed no clinically or statistically relevant effect on HRQoL, even if the study was powered comparably to the current study.[14] However, in both studies, the patient's baseline symptoms and demographics were comparable. Crooks *et al* showed that changes in CAT during the study period were more favourable with higher app usage. In the current study, results of the frequent app user subgroup indicated that increased usage creates greater advantages. Furthermore, this subgroup even increased their PA rather than just maintained it. Hence, it seems that increasing adherence motivation might be a key to achieving favourable results in mHealth app usage by patients with COPD. The finding that uptake of and adherence to digital health

intervention is indeed a challenge in patients with COPD was also confirmed.[36] It is quite conceivable that the use of the app can be beneficial even without prior rehabilitation. This is the subject of the current study and will be reported in the future.

App usage in the current study was sustained over the observational period in most participants in the IG. In this context, previous trials of digital health interventions for PR have repeatedly shown that adherence to the intervention is crucial for favourable outcomes, but adherence is difficult. Previous studies have reported that 28% of patients do not use an app after 1 month (40% at 3 months).[12 13] Long-term adherence of >3 months for digital interventions has only been assessed by a few trials but seems to be a remarkable challenge in those studies with below 20% of participants completing the 6-month programme.[37] The long-term usage rates in the current study suggest acceptable patient engagement throughout the observational period.

The observational period of our study suggests that using a digital health tool maintains PA after PR during an observational period of 6 months. This exceeds the observational periods of previous studies that have investigated the effect of digital tools on self-management in patients with COPD, which ranges mostly from 6 to 12 weeks.[2] Implementing a long observational period is important since continued use and sustained demonstration of positive clinical outcomes of digital health tools have been described as a problem that needs to be addressed.[36]

This study has some limitations. First, the sample size was small. However, the statistical considerations according to the primary endpoint assumed a total sample size of 52 patients. In this study, the results of 60 patients were finally analysed, allowing for appropriate interpretation of the primary endpoint. However, in consequence, additional studies with larger sample sizes will help elucidate the effects of the intervention in broader settings. Second, more than three other sites were asked to participate; however, due to several reasons (eg, no sufficient inpatient PR case load in COPD and no adequate research infrastructure),
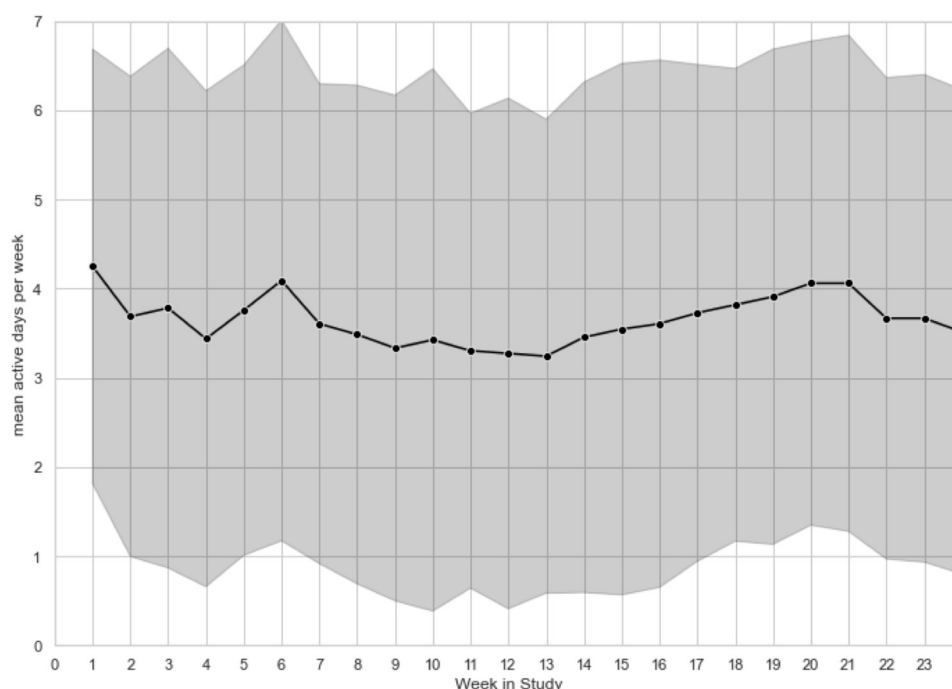

Figure 7 Usage rates per week during the observational period. Mean values are indicated by the black line and dots; SDs are indicated by grey bars.

only two sites were eligible. Third, the results of this study may not be generalisable to a broader population of patients with COPD. According to the aim and the defined inclusion criteria of the study, a preselection of patients in the COPD rehabilitation population was necessary, showing sufficient verification in mobile technology. Hence, even though the authors tried to mitigate this by offering smartphones and a corresponding education as part of the intervention, the study was mainly limited to smartphone users.

Fourth, the nature of the intervention made blinding of the study participants and study staff impossible. Although this problem is commonplace in rehabilitation trials, the lack of blinding is a limitation. To reduce the risk of bias, other procedures such as proper allocation concealment were implemented to ensure rigour and reproducibility. Selection bias may have been introduced in the study through the screening criteria which might select for participants compliant with the study intervention; this may have an effect on adherence and patient engagement. Fifth, while the study showed significant benefits of the intervention over an observational period of 6 months, the effects during a longer observational period like 12 months have not been assessed.

CONCLUSIONS

Digital interventions are an interesting option to support the management of chronic conditions such as COPD. For these digital interventions to be meaningful, integration into the existing healthcare landscape is paramount, and it may provide benefit of increasing the uptake of digital delivery of PR overall. This study reveals how a digital intervention can be used to supplement existing care by closing gaps in the existing healthcare landscape. However, to make a general recommendation on the benefit of an app as a maintenance programme after PR in patients with COPD, further studies are required.

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SUPPLEMENT

Original article

Using a smartphone application maintains physical activity following pulmonary rehabilitation in COPD patients: a randomised controlled trial

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Overview

- Inclusion and exclusion criteria
- Screening period
- Study schedule
- Study period
- Description of the KAIA COPD App

- Figure S6: Contents of the KAIA COPD App
- Figure S7: Smartphone with the KAIA COPD App and Polar A370® Watch
- Table S7: Intervention subgroup analysis (n=13, "Frequent-App-User" IG, intervention subgroup vs. control group, CG) from baseline to visit 8
- Safety endpoints
- Table S5: Adverse and severe adverse events in the intervention (IG) and control group (CG)
- **Table S8: Overview of achieved and set physical activity goals**
- **Table S9: Results of the intervention group in comparison to the minimal clinically important differences**

Inclusion and exclusion criteria

Inclusion criteria

- Diagnosis of COPD was defined as forced expiratory volume in 1 s/forced vital capacity (FEV1/FVC) < 70% predicted, FEV1< 80% predicted after bronchodilation, with or without chronic symptoms (such as cough and sputum production) corresponding to GOLD stage II–IV COPD patients who are willing and can sign the informed consent form for the use of their pseudonymised clinical data within the scope of the present interventional trial.
- Patients with COPD who have completed a comprehensive inpatient pulmonary rehabilitation program for an average duration of 3 weeks (which is a common concept in Germany).
- Completion of the screening period and fulfilment of the randomisation criteria as defined by the protocol.
- Ability to use a smartphone and smartphone apps.
- Willingness to wear an activity tracker during the 6-month study period.
- Age ≥ 40 years
- Familiar with German language to understand the study material, assessments, and contents of the COPD app.

Exclusion criteria

- Patients unable to adhere to the exercise training program due to physical, cognitive, or safety reasons, as judged by the investigators, such as lower limb joint surgery

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within the preceding 3 months, unstable cardiac diseases, predominant neurological limitations, and planned surgical or other interventions disturbing the study intervention.

- Significant psychiatric disorders, legal incapacity, or limited legal capacity.
- Patient participation in another clinical trial with an investigative medication within 30 days prior to the study entry.
- Patients already using the KAIA COPD app.

Randomisation and allocation concealment

Allocation concealment was maintained during the study, as the randomisation lists were kept separate from study sites, and only after confirmation of informed consent of a participant, group allocation was communicated to the study sites. Randomisation was performed by generating blocks of varying sizes stratified by participating sites.

Sleep parameters

Sleep data for the endpoints sleep efficiency (in %) and total sleep time (in hours) were measured by the Polar A-370 watch and extracted for all participants.

Screening period

During the recruitment period, all COPD patients admitted to PR who were interested in participating in clinical trials were screened for eligibility and informed about the on-going study by verbal and written information provided by the Principal Investigator or his Deputy. After obtaining informed consent, participants were instructed to wear an activity tracker for at least 20 h each day, followed by four 20-min structured training sessions. Training sessions were conducted to educate the participants on the use of the study equipment and to perform the necessary assessments, which were sent via the provided smartphone. After an initial screening period of 7-14 days, eligibility was judged by the local investigators based on the inclusion/exclusion criteria (participants regularly wearing the activity tracker and completing the training program). When participants fulfilled these requirements, they were deemed eligible for the study.

Table S6: Study schedule in detail

Data to be recorded	Screening-Period (V1) (duration 8-10 days) Enrolment / Allocation		V2 / Baseline (day 5-8)	V3 30 ± 5 days	V4 60 ± 5 days	V5 90 ± 5 days	V6 120 ± 5 days	V7 150 ± 5 days	V8 180 ± 5 days
Informed Consent	X								
Inclusion, exclusion and randomization criteria	X		X						
Demographic Data	X								
Medical History	X								
COPD Treatment History	X								
Adverse Events / Severe Adverse Events	X	X	X	X	X	X	X	X	X
Compliance Check		X	X	X	X	X	X	X	X
Telephone-Call				X	X	X	X	X	X
Email-Link sent to the participant			X	X	X	X	X	X	X
Exacerbations	X		X	X	X	X	X	X	X
Physical Activity Tracker	X	X	X	X	X	X	X	X	X
COPD-App usage		X	X	X	X	X	X	X	X
Individual Goals			X	X	X	X	X	X	X
CAT			X			X			X
HADS			X			X			X
CRQ			X			X			X
Feeling-Thermometer			X	X	X	X	X	X	X

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One-Minute Sit-to-stand Test			X			X			X
Satisfaction with the App			X			X			X
Concomitant Medication / Change in medication	X		X	X	X	X	X	X	X

CAT, COPD Assessment Test; CRQ, Chronic Respiratory Questionnaire; HADS, Hospital Anxiety and Depression Score; V, visit; App, application

Detailed study schedule

Study period

Every 2 weeks, a follow-up phone call was made by the study staff and ePROs regarding exacerbations, safety (adverse events [AEs] or severe adverse events [SAEs]), device deficiencies, and patient feedback were collected. No medications were prohibited during the study. Any change in concomitant medication was recorded during regular follow-up phone calls. Daily steps were automatically collected by the activity tracker and were imported into the study-specific electronic case report form (eCRF) system. Participants in the IG were supplied with a smartphone and access to the application together with the activity monitor, while the CG was supplied with a smartphone (without the app) and activity monitor. The smartphone was used in both groups to synchronise daily step data and collect questionnaires as described above. All study-related equipment was collected from the participants at the end of the study period.

Description of the KAIA COPD App

The KAIA COPD-App is a multiplatform smartphone application developed by KAIA Health Software GmbH (Munich, Germany) and a CE-marked class I medical device in Europe. It is indicated for self-management and exercise training in COPD patients. The software is available on the Apple App Store (iOS) and the Google Play Store. The app provides daily exercises according to the resulting user profile from a selection of relevant disciplines in PR, i.e., psychology, physiotherapy, and patient education, as recommended by

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international medical guidelines. Furthermore, users have to confirm that they are physically able to perform the exercises and that they have no contraindications to exercise therapy.

The daily exercises include the following elements:

• Physical exercises for strength and mobility training delivered in short videos.

• Patient education based on established patient guidelines.

• Mindfulness techniques for disease coping.

The user is presented with one exercise per category each day but can choose whether he or she wants to complete one, two, or all three elements. The physical exercises were developed by the company and external advisors to be suited for COPD patients, teachable via videos, and completed without additional training. The KAIA algorithm tailors both the duration and the selection of the exercises to the specific user. Daily physical training includes exercises focused on exercise tolerance and muscle function. The exercises are taught by video tutorials. A countdown timer informs about the duration of the exercise. A standard exercise unit consists of five units, but this may vary. The participants rate the exercises daily on difficulty. The exercises alternate between mobilizing and strengthening exercises. Selection, frequency of training, duration of training sessions, and intensity are based on recommendations of the current guidelines.

Figure S7: Contents of the KAIA COPD App

Psychosocial Support   Physical Exercises   Patient Education
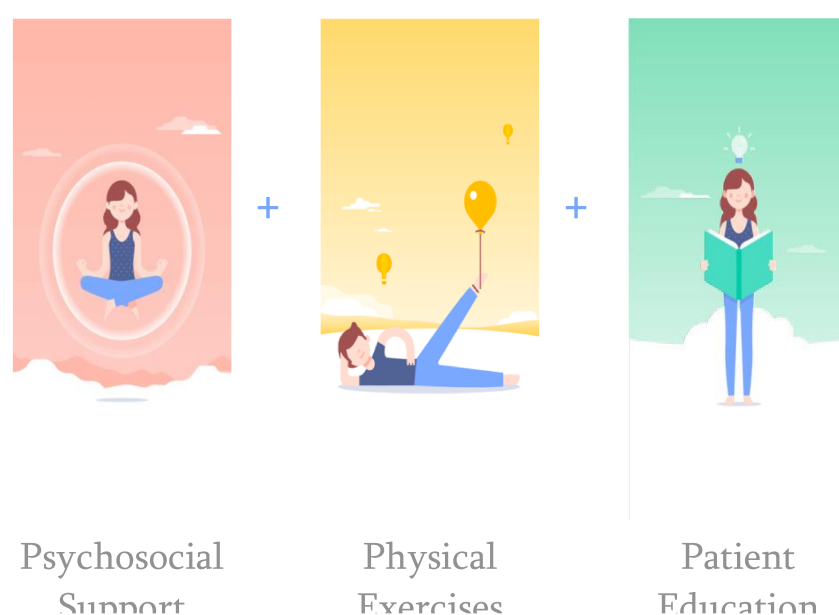
Figure S8: Smartphone with the KAIA COPD App and Polar A370® Watch
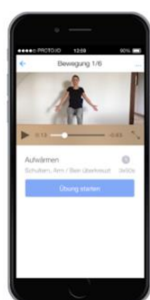
Table S7: Intervention subgroup analysis (n=13, "Frequent-App-User" IG, intervention subgroup vs. control group, CG) from baseline to visit 8

Change from Baseline to Visit 8	Frequent-App-User (IG)	CG	p-value	test
n	13	30		
Change in steps (median [IQR])	1092 [-1036, 2318]	-1173 [-3813, -94]	0.006	nonnorm
Change in CAT (median [IQR])	-3.00 [-10.00, -1.00]	5.00 [0.00, 7.00]	<0.001	nonnorm
Change in STST (median [IQR])	5.00 [0.00, 9.00]	2.00 [-4.00, 8.00]	0.191	nonnorm
Change of CRQ Dyspnea subdomain (median [IQR])	0.20 [0.00, 0.60]	-0.80 [-1.60, -0.25]	0.001	nonnorm
Change of CRQ Fatigue subdomain (median [IQR])	0.00 [-0.25, 0.50]	-0.75 [-1.50, 0.00]	0.029	nonnorm

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Change of CRQ Emotional Function subdomain median [IQR])	-0.43 [-0.57, 0.00]	-0.29 [-1.14, 0.29]	0.754	nonnorm
Change of Mastery subdomain (median [IQR])	0.25 [0.00, 0.50]	-0.25 [-1.00, 0.25]	0.026	nonnorm
Change of total CRQ (median [IQR])	0.02 [-0.22, 0.26]	-0.49 [-1.19, 0.08]	0.015	nonnorm
HADS-A (median [IQR])	0.00 [-2.00, 1.00]	0.00 [-1.00, 3.00]	0.223	nonnorm
HADS-D (median [IQR])	0.00 [-2.00, 2.00]	1.00 [0.00, 5.00]	0.055	nonnorm

"Frequent App User" was defined as a participant using the application at least four times a week for at least 70% of the weeks during the study.

Abbreviations: CAT, COPD Assessment Test; CRQ, Chronic Respiratory Questionnaire; HADS, Hospital Anxiety and Depression Score; HADS-A, score for the Anxiety Domain of the HADS; HADS-D, score core for the Depression Domain of the HADS; STST, One-Minute Sit-to-Stand Test

Safety endpoints

The overall number of AEs and SAEs reported during the study is shown in Table S5. There was no detectable difference between the groups in both overall AEs (p=0.54) and SAEs (p=1.00). No SAEs were related to the study intervention. No participants died during the observational period. The most frequent AEs reported were COPD exacerbations, chest infections, myalgia, and localised dermatitis. There was no significant difference in the distribution of AEs. While 117 device deficiencies were recorded, according to the definitions in the study protocol, no serious device deficiencies leading to AEs or SAEs occurred (Table S5).

Table S5: Adverse, severe adverse events, and device deficiencies in the intervention (IG) and control group (CG)

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	IG	CG	p-value
Adverse Events (n)	53	44	0.53
Severe Adverse Events (n)	10	9	1.00
COPD Exacerbations (n)	17	12	
Chest infections (n)	2	5	
Myalgia (n)	5	0	
Dermatitis, localized (n)	0	4	
Device Deficiencies (n)	N/A	117	
Serious Device Deficiencies (n)	N/A	0	

N, number; p-value indicates the result of a Chi-square test; N/A not applicable

Physical activity goals

Table S8: Overview of achieved and set physical activity goals

Weeks where activity goals were identified n (%)	773 (100)
Weeks where activity goals were reached n (%)	455 (58.9)

n, number

Table S9: Differences for outcome parameters between intervention group and control group at visit 8 in comparison to the minimal clinically important differences (MCID)

Assessment	Result	MCID
Steps per day	+1911	+600-1100 [S1]

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CAT points	-4.59	-2 (-3)[S2]
HADS-A points	-0.91	-1.7 [S2]
HADS-D points	-2.35	-1.5 [S2]
CRQ		
-Dyspnea points	+0.85	+0.5 [S3]
-Fatigue points	+0,78	+0.5 [S3]
-Emotional functioning points	+0.6	+0.5 [S3]
STST repetitions	+3,21	+3 [S4]
Feeling thermometer degrees	+7.5	+5 [S5]

CAT, COPD Assessment Test; CRQ, Chronic Respiratory Questionnaire; HADS, Hospital Anxiety and Depression Score; HADS-A, score for the Anxiety Domain of the HADS; HADS-D, score core for the Depression Domain of the HADS; STST, One-Minute Sit-to-Stand Test

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