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FULL RESEARCH PAPER
Cardiac rehabilitation

Lifestyle behaviour change of patients following cardiac rehabilitation: the BENEFIT intervention study with one-year follow-up

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Aims The majority of people with cardiovascular disease do not maintain a healthy lifestyle. To help patients implement behaviour change at home, the BENEFIT programme was developed as an addition to cardiac rehabilitation (CR) care.

Methods and results Using a cluster non-randomized controlled trial design involving seven CR centres, we examined whether intervention group patients ($n = 587$) showed increased improvements in health behaviour change compared with control group patients ($n = 298$) who (only) received a multidisciplinary, comprehensive CR programme. Physical activity, smoking, alcohol use, diet, stress, and sleep were assessed at the start and after finishing CR (short-term) and at 1-year follow-up (long-term). Core of the intervention was access to an advanced eHealth platform consisting of functionality for daily goal monitoring, access to lifestyle interventions, personal coaching and a reward programme.

Findings The standard CR programme improved most lifestyle behaviours, while the intervention led to additional short-term changes in vegetable intake ($t = 2.00$, $P = 0.023$), work-related stress ($z = -2.97$, $P = 0.002$), and sleep hours ($t = 2.57$, $P = 0.005$). Finally, in contrast to the control group ($t = 1.88$, $P = 0.415$), the intervention group significantly increased its physical activity long-term ($t = 5.04$, $P < 0.001$) exercising 42 min more per week, yet this group-interaction effect showed only a trend ($t = 1.55$, $P = 0.061$).

Conclusion While comprehensive CR care led to improvements in most lifestyle behaviours, the BENEFIT programme demonstrated additional benefits, particularly in physical exercise, dietary habits, stress reduction, and sleep, across a diverse CR-patient population. These findings underscore the potential of integrating eHealth solutions as an effective supplement to traditional CR care.

Lay summary This study examined whether adding an eHealth lifestyle programme (the BENEFIT programme) to standard cardiac rehabilitation (CR) care could help heart disease patients make and maintain healthier lifestyle changes at home. This is

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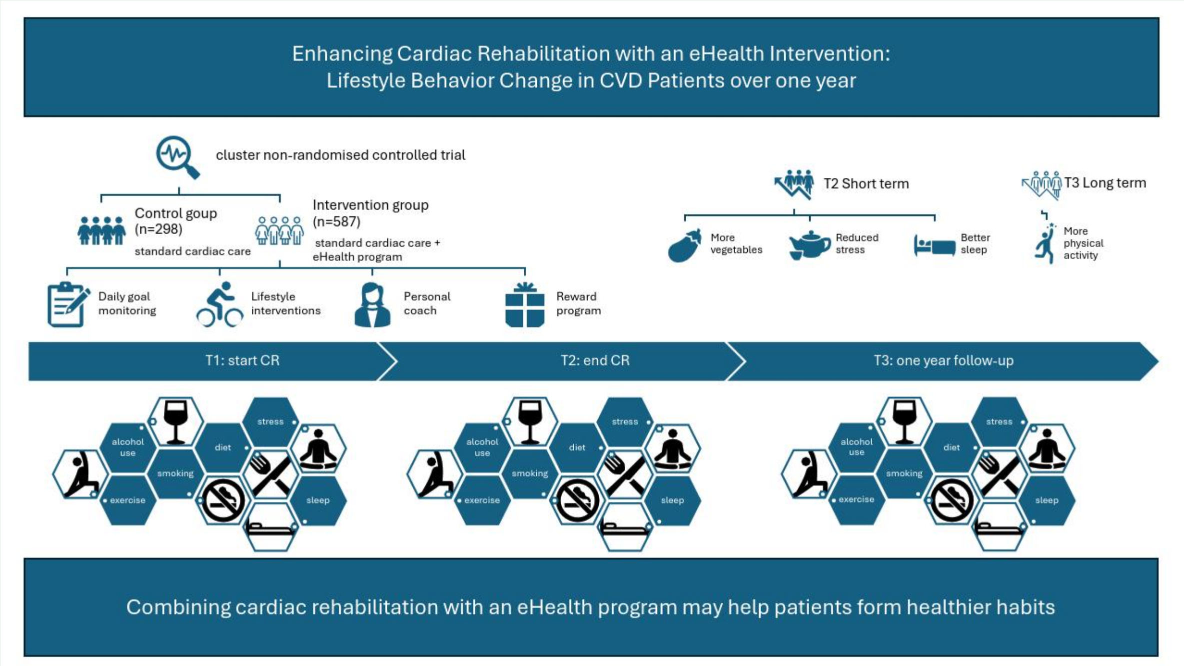
important as many patients struggle to form healthy lifestyle habits. The BENEFIT programme was created to help patients during and after CR, by offering an online platform with tools like daily goal tracking, personalized coaching and a reward system to motivate healthy habits. This study followed 885 patients to track their progress over the course of a year.

Key findings

- Short-term benefits: Patients who used the eHealth programme, in addition to CR care, made more improvements in their diet (eating more vegetables), experienced less work-related stress, and had better sleep compared with those who only received standard CR care.
- Long-term benefits: One year after starting CR, patients who participated in the eHealth programme maintained higher levels of physical activity, exercising on average 42 min more per week compared with when they started CR, while those in the standard CR group exercised on average 9 min more per week.
- These results suggest that combining an eHealth programme with traditional CR may help patients to better manage their health at home. However, more research is needed to identify which patients benefit the most and how the programme can be adapted to meet individual needs.

Graphical Abstract



Keywords Cardiac rehabilitation • Lifestyle • Modifiable risk factors • Health behaviour change • Cardiovascular disease • Intervention • Coaching

Introduction

Although cardiovascular diseases (CVD) are largely preventable, they still affect nearly 49 million individuals in the European Union (EU), rendering it the primary cause of mortality across Europe.[1] The core of effective cardiovascular risk management is modification of risk factors through the improvement of lifestyle behaviours,[2] which forms the basis of cardiac rehabilitation (CR) programmes worldwide.[3,4] The benefits of CR are widely acknowledged,[5,6] with numerous studies demonstrating that implementing different lifestyle recommendations, such as increasing physical activity and smoking cessation, significantly enhances the prognosis of CVD.[1,2] However, evidence also shows that maintaining a healthy lifestyle in the long-term is challenging and that the majority of people with CVD relapse into old habits.[7,8] Maintaining a healthy lifestyle is incredibly difficult as unhealthy behaviours are only inhibited and newly learned habits are often context dependent.[9] Traditional CR programmes, while effective for initiating change in clinical settings,[5,6] do not replicate the home environment where patients must sustain these changes.[9] Encouraging patients to practice lifestyle recommendations at home and providing accessible tools can help prevent relapse and support long-term habit formation.[9–11] Extending learned behaviours from the CR setting to the home environment is therefore crucial for preventing relapse and fostering effective habit formation.[9]

For CVD patients to maintain a healthy lifestyle in the long-term, it is also crucial for CR programmes to move away from a one size fits all approach.[12] Instead, CR programmes need to take a holistic approach, emphasizing the importance of addressing both physical health and psycho-social support and addressing a wide range of lifestyle risk factors (e.g. physical activity levels, smoking behaviour, alcohol consumption, diet, stress levels, and sleep habits) important in managing CVD.[12] For example, using clinical prediction models based on a personalized risk assessment, lifestyle recommendations can be tailored to patients specific needs and preferences ensuring a patient-centred approach.[13,14] Healthcare technologies such as wearable devices and eHealth platforms are increasingly integrated in CR care, which can be used to facilitate practicing personalized lifestyle recommendations at home by enabling the remote monitoring of lifestyle behaviours and health outcomes of patients.[12] These technologies allow for personalized adjustments to be made to lifestyle intervention plans and address the diverse needs of patients, a factor shown to enhance engagement and providing possibilities to prevent habit relapse as well as preventing overtreatment or under treatment of patients.[12] To conclude, offering lifestyle interventions at home, tailored to patient's specific modifiable risk factors and according needs and preferences may lead to less relapse and more meaningful recovery goals.[15] This approach has the potential to increase the patient's motivation and engagement in maintaining a healthy lifestyle in the long-term.

The current study

To facilitate maintenance of a healthy lifestyle for CVD patients, we founded a public-private partnership to develop our BENEFIT intervention programme as an addition to standard CR care in the Netherlands.[16] Core of the BENEFIT intervention is access to a Personal Health Application (PHA) consisting of functionality for daily goal monitoring, (evidence-based) lifestyle interventions, personal coaching, and a reward programme aimed at stimulating a wide range of health behaviours and therapy adherence.[17] These features are grounded in well-established behaviour change techniques (BCTs), such as goal setting, feedback, and rewards, which have consistently been shown to improve adherence and long-term maintenance of healthy behaviours in similar populations.[18,19] The goal of the current study is to examine the added value of the BENEFIT intervention (i.e. additionally providing CVD patients with a PHA and lifestyle coaching sessions) in comparison with a control group that receives standard CR care only, on changes in healthy lifestyle behaviours, related health outcomes and motivation for lifestyle change. Specifically, we will investigate two research questions: (i) upon completion of CR, does the BENEFIT intervention programme lead to additional improvements in healthy lifestyle behaviours for CVD patients? (ii) One year after the start of CR, do CVD patients who received the BENEFIT intervention sustain their healthy lifestyle behaviour changes? We hypothesized that patients in both the control and intervention groups would show improvements in their lifestyle behaviours (including exercise, smoking, alcohol use, diet, stress, and sleep) as a result of the multidisciplinary, comprehensive CR programme (i.e. standard care). However, we also expect that the intervention group will demonstrate greater improvements in at least two of these lifestyle domains compared with the control group (primary outcomes). This expectation is based on the additional support offered by the lifestyle coach and the eHealth platform's features which are grounded in well-established BCTs proven to promote sustained behaviour change. Recognizing that most patients will likely prioritize physical fitness and diet or stress management over other lifestyle domains such as quitting smoking or reducing alcohol use, we cautiously hypothesize that the intervention will result in greater improvements in at least two lifestyle domains. For both the control and intervention groups, we do not expect changes in their related health outcomes (BMI and waist circumference; secondary outcomes). Additionally, we expect improvements in motivation, self-efficacy, and goal achievement for both groups, with greater improvement expected in the intervention group compared with the control group (secondary outcomes).

Methods

Design and sample

This study is a longitudinal study where all patients were followed-up for 1 year and designed as a cluster non-randomized controlled trial. Participating were seven CR centres providing multidisciplinary, comprehensive CR care, according to Dutch guidelines.[20] The centres were located in metropolitan, urban and rural areas across the Netherlands. Patients were recruited in these centres as part of the BENEFIT study between January 2020 and May 2022, and we reported on these patients' characteristics at baseline in a preceding paper.[21] However, due to the outbreak of COVID-19, national restrictions were imposed such that in March 2020, face-to-face CR was halted and baseline measurements and the intervention were interrupted. Thus, in February 2021, we initiated a new phase of the study with five centres beginning in the control condition, where they provided only standard CR care to their patients. At the same time, two centres started in the intervention condition, providing the eHealth platform and additional tele-coaching (i.e. via chat, telephone, or screen-to-screen) in addition to standard CR care. Importantly, data collection for both conditions took place between February 2021 and May 2022, ensuring that measurements for both groups occurred within the same timeframe.

The two centres that started in the intervention condition were deliberately chosen for the initial implementation of the BENEFIT intervention programme due to their readiness in terms of both personnel and facilities, including having trained staff capable of delivering the additional eHealth intervention. A few months later, once all centres were assessed to be prepared for the intervention, all centres switched conditions and all new patients received the corresponding new care. However, this transition did not occur simultaneously across all centres. Each centre, along with its staff, needed to be adequately prepared to incorporate the intervention into its standard care routine before making the switch. Importantly, patients were assigned to only one condition, as there was no crossover; they remained in the same condition throughout their care.

After referral, CR administration contacted patients by phone to make an appointment for the intake interview for the CR programme. After an appointment had been set, patients received an email with confirmation of the date and time of the appointment together with a link to create an account for their PHA. This email was sent to patients in both conditions as the PHA was also used for the participants in the control group to fill out online questionnaires before the CR intake interview, which was part of standard CR care for all patients. Thus, the PHA only provided access to the questionnaires for patients in the control condition, while for patients in the intervention condition, and the PHA gave access to all health behaviour interventions and according functionality. Subsequently, participants were asked to provide informed consent to share their data for research purposes. To ensure a maximum response rate, patients that failed to be registered on the PHA or did not manage to fill out the questionnaires were contacted a few days in advance of the intake interview by phone in order to motivate them and/or offer technical support.

To qualify for participation in the study, patients were required to meet two criteria: (i) possess a basic understanding of the Dutch language, as both the PHA and survey were conducted in Dutch, and (ii) having an email address for receiving the registration invitation for the PHA. We conducted *a priori* power calculations using GPower.[22] These calculations aimed to detect a medium effect size of the intervention compared with care-as-usual across various lifestyle behaviours. Based on these estimates, a sample size of 102–112 patients would provide 80% power to detect a medium effect size with an alpha level of 0.05 (one-sided), depending on the specific analysis.[23] To account for the hierarchical structure of patients nested within CR centres, we adjusted the required sample size using an estimated intra-class correlation (ICC) of 0.05 from the literature,[24] and an assumed mean cluster size of 100. This adjustment increased the required sample size to ∼600–700 participants. A total of 1160 patients enrolled in CR who were deemed eligible for inclusion (see *Figure 1* Flowchart). Out of the 1160 enrolled patients, 885 (76%) completed online registration, provided informed consent to participate in the study, did not drop out of CR, and at least partially completed the survey(s).

Ethics approval for this study was obtained from the Psychology Research Ethics Committee (registration number 2020-04-14-A.W.M.Evers-V2-2271) and the study is listed in the Netherlands Trial Register (number NL8443). This study, including the hypotheses, design, data analysis plans and initial power calculations, is also pre-registered in OSF registries (https://doi.org/10.17605/OSF.IO/AEB2X). Although this study is designed as a cluster non-randomized controlled trial, the reporting of this study was guided by the Consort 2010 checklist for reporting randomized trials.[25]

Standard CR care

CR care in the Netherlands follows the standards set in The Dutch Multidisciplinary Cardiac Rehabilitation Guideline,[20] and offers an out-patient, multidisciplinary programme which focuses on physical, emotional and social recovery after a cardiac event and secondary prevention by providing patients information and working on set goals. Based on Dutch CR guidelines, the length of the programme is 3 months for most patients,[20] however, the programme may be longer for some patients because of inequalities in the patient population and (unforeseen) circumstances. For example, some patients may require more exercise sessions with a trained professional to reach certain physical activity goals while other patients may have fewer appointments over a given period due to early achievement of rehabilitation goals (leading to a shortened CR programme), or because of illness or additional hospital visits (leading to an extended CR programme). The CR programme consists of two standard group modules: (i) FIT-module, which consists of one to two times a week physical training (with a total of ∼12 sessions of 1 h) under supervision of a specialized physiotherapist and (ii) PEP-module, which stands for 'psycho-educational

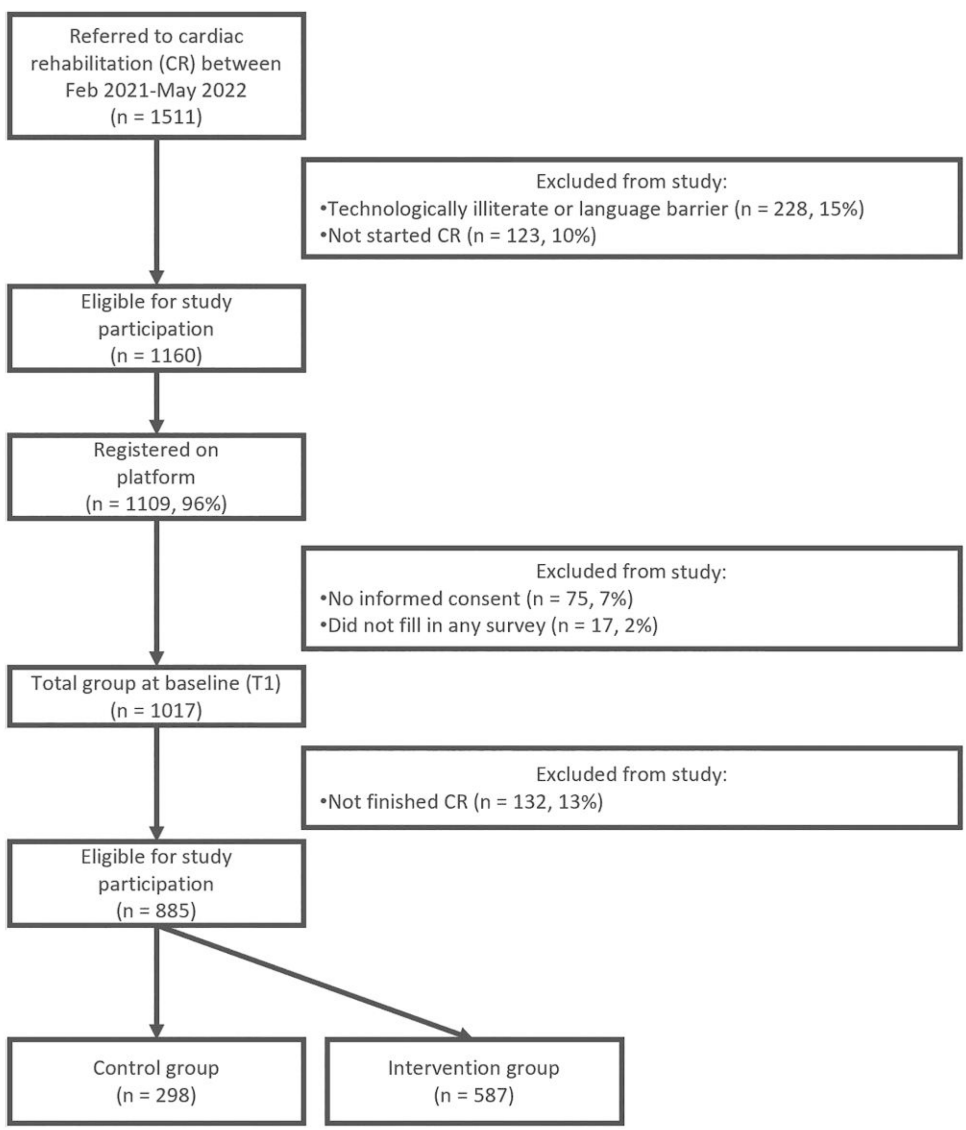


Figure 1 Flowchart of participants in the study.

prevention module', consisting of either two to three interactive lifestyle and behaviour change education sessions of 2 h and/or two to three interactive stress management sessions of 2 h provided by an expert in this field. In addition, included in the CR programme are individual consultations of a dietician, psychologist and/or social worker, if indicated (please see also *Table 1*).

The BENEFIT intervention programme

The BENEFIT intervention programme (see also *Table 1*) centres around an online care platform, the PHA, co-created with users and other stakeholders and described in detail in a previous publication.[17] This application or platform uses a wide range of effective BCTs such as offering features for goal setting, action planning and daily health and behaviour monitoring with personalized automated feedback.[18,19] It also grants access to a wide range of evidence-based lifestyle interventions including previously developed lifestyle and cognitive behavioural therapy interventions by the research group and those provided by external partners such as expert organizations. The PHA additionally contains a loyalty programme, designed to encourage and enable sustainable lifestyle improvements. Specifically, participants earn points by engaging with specific platform features or challenges. These points can be redeemed for financial rewards focusing on health-related products and services. Examples include discounts on medical equipment (e.g. blood pressure monitors and saturation metres), discounts on lifestyle and health-related books, gift cards and additional lifestyle coaching. Most participants who utilized this loyalty programme opted to purchase a blood pressure monitor at a reduced price. In addition to financial rewards, social rewards were also incorporated in the platform by using positive reinforcement through automated praise messages that acknowledge patients' progress in completing lifestyle challenges. Finally, a personal lifestyle coach is connected to the platform to answer any questions, provide platform guidance and inspire patients to actively use the platform. Patients are encouraged to have a monthly phone call with their personal coach during and after CR. This comprehensive healthy living programme makes it possible to tailor lifestyle interventions to the specific needs and preferences of users, aiming to foster greater engagement and active use.[26,27] The programme also promotes self-management of a healthy lifestyle at home by encouraging patients to measure health indicators (such as blood pressure) themselves, empowering patients to take an active role in managing their health.[17,28,29] By rewarding a broad range of health behaviours (such as exercising, abstaining from smoking, alcohol use, etc.) and adherence behaviours (attending prevention programmes and showing up for health appointments) the programme aims to integrate care and non-care settings and facilitate embedding the new lifestyle in everyday life.

Measures

This study utilized data routinely collected from all patients undergoing CR. Reasons for referral such as treatment and diagnosis were taken from patients' medical files. Sociodemographic information such as patients' age and sex were established by healthcare professionals or through the survey on the PHA. As part of this routine data collection, we focused on three key measurement points. At these points, participants were requested to fill in questionnaires within the PHA, which were both integral to the standard care process and specifically analysed for the study: (T1) at baseline, around the start of CR, (T2) after the ending of CR (∼3–6 months after the start; short-term), and (T3) ∼1 year after the start of the baseline measurement (long-term). Primary outcome measures were changes in lifestyle behaviours. Secondary outcome measures were physical health, motivation, self-efficacy, and support for lifestyle change.

Table 1 Description of standard cardiac rehabilitation modules and intervention modules

	Mode	Number	Content
CR modules (standard care)			
Intake interview	Individual, human-guided	1	
FIT-sessions	Individual, human-guided	Max 12	Physical training under supervision of a specialized physiotherapist
PEP-sessions	Group, human-guided	Max 3	An interactive lifestyle modification and stress management programme
Psycho-social care	Individual, human-guided	Optional	Consultations with a dietician, psychologist and/or social worker
Outtake	Individual, human-guided	1	Evaluation
Intervention modules			
Lifestyle tele-coaching	Individual, human-guided	Max 10	By phone: coaching using motivational interviewing and behaviour change techniques, relapse prevention
Lifestyle tele-coaching	Individual, human-guided	No limit	By chat: short questions regarding lifestyle interventions
Information	Individual, ehealth		Information on disease, content of CR
Psychoeducation	Individual, ehealth		Self-help modules
Tracking and monitoring health and behaviour	Individual, ehealth		Feedback on health and behaviour
Feedback on health and behaviour	Individual, ehealth		Automated feedback on health and behavioural goals
Interventions (challenges) for exercise	Individual, ehealth	4 types	e.g. Step count, exercises at home
Interventions (challenges) for smoking	Individual, ehealth	2 types	Quitting and cut down smoking
Interventions (challenges) for alcohol use	Individual, ehealth	2 types	Quitting and cut down alcohol consumption
Interventions (challenges) for diet	Individual, ehealth	6 types	e.g. less salt and sugary drinks, more vegetables and fruits
Interventions (challenges) for stress	Individual, ehealth	6 types	e.g. meditating, positivity, back to work
Interventions (challenges) for sleep	Individual, ehealth	8 types	e.g. sleep diary, evening ritual, breathing exercises
Resources	Individual, ehealth	variable	External providers of lifestyle interventions

Lifestyle behaviours

Lifestyle behaviours were assessed using the Personal Health Check survey within the PHA. Originally developed as a web-based cardiovascular risk assessment tool used by over 1250 Dutch organizations,[13] the survey was adapted for use in CR and has been published previously in research with cardiac patients.[21] This adapted questionnaire is also applied in other health domains, such as for patients with psoriasis.[30] Its foundation in established lifestyle recommendations lends support to its face and content validity. We distinguished six domains of lifestyle behaviours: (i) physical activity (i.e. mean minutes per week of moderate-intense exercise); (ii) smoking (mean number of cigarettes per day, smokers only); (iii) alcohol use (mean number of alcoholic beverages per week); (iv) diet (mean spoons of vegetables (1 spoon ≈ 50 g) and pieces of fruit consumed per day (1 piece ≈ 100 g)); (v) stress (mean stress at home and stress at work (little (0) = never or sometimes vs much (1) = multiple times or always)), and (vi) sleep (mean hours of sleep per day). Additionally, the survey contained items regarding height, weight, and waist circumference. As all assessments were online, skip logic was used to shorten and simplify the survey in such a way that only relevant items needed to be rated by patients. The rating scale for each item varied depending on the type of question (i.e. yes/no; Likert scale; number of days, etc.). Some questions were combined to create specific subscales (e.g. 'minutes of exercising' and 'days per week exercising' were combined to calculate min/week exercising). As all health behaviours were self-reported, unrealistic values were removed (i.e. max. minutes of exercising per week was set at 900 min; max smoking was set at 60 cigarettes per day; max alcohol was set at 20 alcoholic beverages per day; max spoons of vegetables was set at 10 per day; max pieces of fruit was set at 10 per day; min hours of sleep was set at 4 h and max at 15 h).

Physical health

Modifiable risk factors for CVD included BMI and waist circumference, which were routinely assessed by a healthcare professional during the CR intake and taken from medical records. Waist circumference (measured in cm) was assessed by placing a tape horizontally at the mid-point along the mid-axillary line, situated between the lower edge of the rib cage and the tip of the hip bone, while the patient was in a standing position. Height and weight were measured wearing light clothes but no shoes, to calculate BMI (kg/m^2).

Motivation, self-efficacy, and support for lifestyle change

Patients were asked to indicate whether they were motivated and able to change their lifestyle regarding one of the six lifestyle domains. If yes, they were asked to define a personal goal concerning this lifestyle domain, for example, the number of steps to take each day if they choose the domain 'exercise'. In addition, we assessed (i) the patients' level of motivation (i.e. 'how motivated are you to reach this goal?'), (ii) the patients' level of self-efficacy (i.e. 'how much confidence do you have that you can achieve this goal, if you try?'), and (iii) the patients' level of social support to reach this goal (i.e. 'to what extent do you feel supported by people close to you to achieve this goal?') on a 11-point Likert scale.

Analyses

Our analyses followed the intention-to-treat principle, reflecting the intervention's flexible, tailored design, which allowed patients to decide how and how often to engage with the platform. This ensured that all patients assigned to the intervention group were included in the analyses, regardless of their engagement level. Analyses were performed in R studio (version 2023.6.0.421). First, χ^2 tests were used to examine baseline differences in clinical and demographic characteristics between the intervention and control groups, applying Yates' continuity correction when appropriate. Second, to test our hypotheses, Linear Mixed Models were applied for continuous outcome variables while Generalized Linear Mixed Models with a logit link function were used for the dichotomous outcome variables. We used the lme4 package (version 1.1–35.1) to analyse differences between the treatment groups (control vs. intervention) and the interaction effect of treatment group with change over time (both fixed effects) for each outcome variable. Patient ID was fitted as a random effect to account for the correlation between repeated measurements of the same patient. Centre-level effects were not incorporated in the model as initial multilevel analyses showed minimal centre-level effects (ICC range <0.01–0.02 for all outcome variables, see *Supplementary Table S1*), and adding this level unnecessarily complicated the models without improving explanatory power. As the distribution of minutes per week exercising was skewed to the right (with many patients who barely exercised), we used a log transformation to reduce skewness.

The lmerTest package (version 3.1–3) was used to provide *P*-values via Satterthwaite's degrees of freedom method. We tested our directional hypotheses using a one-sided approach, while our non-directional hypotheses were tested with a two-sided approach. We deemed a *P*-value of ≤ 0.05 as significant for all analyses. In addition, pairwise comparisons were conducted using estimated marginal means through the emmeans package (version 1.9.0) to test the significance of change in the outcome variable over time (T1 vs. T2 and T1 vs. T3) for each treatment group. These results were corrected for multiple testing using a Tukey adjustment.

Results

Of the 885 CR participants, 619 (70%) were male, with a mean age of 63 years (SD = 11.7; range: 17 to 89 years). Clinical and demographic characteristics of the sample are summarized in *Table 2*. No differences were observed between the control and intervention groups in terms of medical diagnosis, age, family status, educational level, or working status, although slightly more patients in the intervention group reported a middle income. Descriptive statistics (raw means) for primary and secondary outcomes are provided in *Table 3* with hypotheses tested below.

Platform engagement

Log data provided insights into participants' engagement with the eHealth programme over 1 year. Engagement data were available for 581 intervention group patients, with 6 patients excluded due to technical issues. Most participants, 38.9%, logged in between 100 and 150 times, while 34.8% logged in fewer than 100 times, and 26.3% logged in more than 150 times. On average, participants logged in 128.0 (SD = 60.5) times and used the platform 70.0 days (SD = 28.3). Excluding outliers, the average session duration was 7.0 min (SD = 1.6), calculated as the time difference between the start time of the first activity and the start time of the last activity within each session. Specific details on user activities during these sessions are not available.

Primary outcomes: lifestyle improvements after finishing CR (T2) and at 1 year follow-up (T3)

Both groups demonstrated improvements in lifestyle behaviours following multidisciplinary, comprehensive CR, with further enhancements observed in the intervention group. Detailed analyses concerning improvements in lifestyle behaviours are presented in *Table 4*. Specifically, patients showed significant improvements in exercise in both the short and long-term (T2: + 27 min per week, $P < 0.001$; T3: + 30 min per week, $P = 0.030$), fruit intake (T2: + 8%, $P = 0.019$; T3: + 9%, $P = 0.029$) and reduced stress at home (T2: OR 0.52, 48% lower odds of experiencing stress at home, $P = 0.009$; T3: OR 0.41, 59% lower odds of experiencing stress at home, $P = 0.005$) in both groups. Smoking reduction was also observed, but only in the short-term (T2: −4.2 cigarettes/day, $P = 0.004$), without sustained changes

Table 2 Clinical and demographic characteristics of CVD patients

Variable	Control group *n*	Control group %	Intervention group *N*	Intervention group %	χ^2 (df)	*P*-value
Treatment—diagnosis	**290**		**581**		4.431 (11)	0.956
Percutaneous coronary intervention (PCI)	118	40.7	264	45.0		
Other (o.a. conservative treated ACS and arrhythmia)	53	18.3	88	15.0		
Coronary artery bypass grafting (CABG)	41	14.1	82	14.0		
Heart valve surgery	30	10.3	59	10.1		
ICD/Pacemaker implantation	19	6.6	29	4.9		
Ablation procedure	9	3.1	19	3.2		
Stable angina pectoris (conservative treatment)	6	2.1	10	1.7		
Heart failure (without other indication)	6	2.1	11	1.9		
Thoracic aortic surgery	3	1.0	9	1.5		
Transcatheter aortic valve implantation procedure (TAVI)	2	0.7	5	0.9		
MAZE procedure	3	1.0	4	0.7		
Heart transplantation	0	0.0	1	0.2		
Sex	**298**		**587**		0.207 (1)	0.649
Male	205	68.8	414	70.5		
Age	**298**		**587**		1.180 (3)	0.758
Age <50	38	12.8	75	12.8		
Age 50–59	77	25.8	147	25.0		
Age 60–69	101	33.9	184	31.3		
Age >70	82	27.5	181	30.8		
Family status	**298**		**587**		1.978 (2)	0.372
Partner—living together	214	71.8	436	74.3		
Partner—not living together	24	8.1	33	5.6		
No partner	60	20.1	118	20.1		
Education	**216**		**449**		2.382 (2)	0.304
Low	61	28.2	117	26.1		
Middle	67	31.0	121	26.9		
High	88	40.7	211	47.0		
Working	**298**		**587**		1.886 (4)	0.757
No	154	51.7	282	48.0		
Yes, yet currently 0 h	19	6.4	44	7.5		
Yes, currently 1–30 h	42	14.1	99	16.9		
Yes, currently 31–40 h	56	18.8	107	18.2		
Yes, currently >40 h	27	9.1	55	9.4		
Income per month	**216**		**449**		12.585 (6)	0.050
0–1500 euro	50	23.1	79	17.6		
1501–2000 euro	30	13.9	59	13.1		
2001–2500 euro	30	13.9	66	14.7		
2501–3000 euro	21	9.7	84	18.7		
3001–3500 euro	24	11.1	35	7.8		
>3500 euro	28	13.0	67	14.9		
Rather not say	33	15.3	59	13.1		

Bold values represent main categories, while non-bold values correspond to the respective subcategories.
ACS, acute coronary syndrome; CVD, cardiovascular disease; ICD, implantable cardioverter-defibrillator; MAZE, heart surgery procedure for atrial fibrillation.

at 1-year follow-up ($P = 0.116$). Alcohol intake showed no significant reduction in either group.

For some lifestyle behaviours, the intervention group showed additional improvements beyond those found when participating in standard CR. Specifically, after completion of CR, the intervention group showed significantly more short-term improvements in vegetable intake (T2: + 8%, $P = 0.023$), reduced work-related stress (T2: OR 0.14, 86% lower odds of experiencing stress at work, $P = 0.002$), and increased sleep duration (T2: + 15 min, $P = 0.005$). However, these group differences did not persist in the long-term. At the 1-year

Table 3 Descriptive of lifestyle behaviour raw data across both groups and three time points

		Control group			Intervention group		
		N	Mean/%	SD	*N*	Mean/%	SD
Exercise (min/week)	T1	287	190.90	210.75	562	181.31	203.79
	T2	206	210.62	204.65	325	210.43	168.01
	T3	128	194.64	193.99	217	221.52	215.24
Smoking	T1	40	8.67	8.80	57	6.94	7.42
Cigarettes/day	T2	33	4.41	7.69	33	3.61	5.95
Smokers only	T3	19	5.90	6.57	26	7.12	7.72
Alcohol use (Beverages/week)	T1	297	4.80	7.91	587	4.50	6.54
	T2	211	4.40	5.96	338	3.66	6.46
	T3	136	5.04	6.93	224	3.49	5.45
Vegetable intake (Spoons/day)	T1	292	2.81	1.49	582	2.84	1.43
	T2	211	2.78	1.59	335	3.07	1.62
	T3	133	2.87	1.44	220	3.03	1.40
Fruit intake (pieces/day)	T1	298	1.40	1.05	584	1.40	1.02
	T2	212	1.49	0.97	335	1.50	0.99
	T3	136	1.50	0.99	221	1.48	0.86
Stress at home	T1	298	34.2%		587	32.7%	
High (1)	T2	212	25.9%		338	29.3%	
	T3	136	20.6%		224	23.2%	
Stress at work	T1	298	22.5%		587	24.5%	
High (1)	T2	212	23.1%		338	18.0%	
	T3	136	18.4%		224	15.6%	
Sleep (h/day)	T1	288	7.36	1.42	580	7.35	1.38
	T2	209	7.28	1.23	334	7.49	1.34
	T3	133	7.42	1.20	221	7.37	1.27
BMI (kg/m^2)	T1	298	27.20	4.28	587	27.05	4.75
	T2	212	26.95	3.88	338	27.00	4.52
	T3	136	27.17	4.12	224	26.82	4.06
Waist circumference (cm)	T1	279	100.90	13.09	554	99.98	13.07
	T2	196	99.21	11.60	315	99.87	14.11
	T3	121	101.12	12.30	203	98.75	12.34
Motivation	T1	294	8.19	1.81	484	8.36	1.78
11-point Likert scale	T2	198	7.89	2.28	324	8.23	2.03
	T3	119	7.61	2.13	181	7.91	1.78
Self-efficacy	T1	294	7.29	2.30	484	7.75	1.93
11-point Likert scale	T2	198	7.82	1.89	324	7.95	1.84
	T3	119	7.60	2.19	181	7.92	1.73
Social support	T1	294	7.78	2.55	484	8.06	2.22
11-point Likert scale	T2	198	7.82	2.49	324	7.97	2.31
	T3	119	7.68	2.78	181	7.82	2.18

T1 = baseline; T2 = end of cardiac rehabilitation; T3 = at 1 year follow-up.

mark, overall outcomes were comparable between groups. For exercise, the interaction effect of change over time between groups approached but did not reach statistical significance ($P = 0.061$). Given this trend, we did examine additional pairwise comparisons of within-group changes over time (see *Supplementary Table S2*). These analyses revealed that the intervention group continued to demonstrate additional improvements in exercise levels. While the control group showed no significant improvement in exercise after 1 year (+9 min per week, $P = 0.415$), the intervention group did significantly improve in the long-term (+42 min per week, $P < 0.001$).

Secondary outcomes: physical health, motivation, self-efficacy, and support

Secondary outcomes, including the physical health indicators BMI and waist circumference, as well as measures of motivation, self-efficacy and social support were assessed but we did not find additional benefits for the intervention group beyond those already achieved through multifaceted CR. While BMI remained relatively stable over time, waist circumference decreased in both groups during CR and at follow-up. We observed some differences between the groups in favour of the

Table 4 Linear mixed model analyses of change in primary outcome measures from T1 to T2 and T3, group effects (control vs. intervention) and interaction effects

Outcome	Predictor	Estimate[a]	CI	*t*/*z*-value[b]	*P*-value
Exercise (min/week)	Intercept	1.70	1.59–1.80		
Log10transf.	Group (I)	−0.06	−0.19–0.07	−0.87	0.193
N = 873	T2	0.29	0.15–0.43	4.04	**<0.001**
obs = 1725	T3	0.16	−0.01–0.33	1.88	**0.030**
	Group (I) × T2	0.12	−0.06–0.30	1.32	0.094
	Group (I) × T3	0.17	−0.04–0.38	1.55	0.061
Smoking (Cigarettes/day)	Intercept	8.67	6.33–11.02		
Smokers only	Group (I)	−1.73	−4.79–1.33	−1.12	0.133
N = 97	T2	−4.16	−7.17 – −1.14	−2.71	**0.004**
obs = 208	T3	−2.23	−5.90–1.44	−1.2	0.116
	Group (I) × T2	1.29	−2.87–5.46	0.61	0.271
	Group (I) × T3	2.71	−2.12–7.53	1.11	0.135
Alcohol use (beverages/week)	Intercept	4.84	4.06–5.63		
N = 885	Group (I)	−0.35	−1.31–0.61	−0.71	0.239
obs = 1793	T2	−0.29	−0.85–0.28	−1.00	0.159
	T3	0.03	−0.64–0.70	0.08	0.467
	Group (I) × T2	−0.29	−1.01–0.43	−0.80	0.213
	Group (I) × T3	−0.47	−1.32–0.38	−1.09	0.138
Vegetable intake (spoons/day)	Intercept	2.82	2.64–2.99		
N = 884	Group (I)	0.03	−0.19–0.24	0.23	0.408
obs = 1773	T2	−0.01	−0.18–0.16	−0.11	0.455
	T3	0.08	−0.12–0.29	0.79	0.214
	Group (I) × T2	0.22	0.00–0.44	2.00	**0.023**
	Group (I) × T3	0.07	−0.19–0.33	0.52	0.304
Fruit intake (pieces/day)	Intercept	1.40	1.28–1.51		
N = 884	Group (I)	0.00	−0.14–0.14	−0.04	0.485
obs = 1786	T2	0.11	0.01–0.21	2.07	**0.019**
	T3	0.12	−0.00–0.23	1.90	**0.029**
	Group (I) × T2	−0.02	−0.15–0.10	−0.35	0.364
	Group (I) × T3	−0.06	−0.21–0.09	−0.74	0.230
Stress at home	Intercept	0.26	0.16–0.43		
Low (0) vs. high (1)	Group (I)	0.87	0.51–1.49	−0.51	0.307
N = 885	T2	0.52	0.30–0.89	−2.38	**0.009**
obs = 1795	T3	0.41	0.21–0.80	−2.59	**0.005**
	Group (I) × T2	1.49	0.75–2.94	1.14	0.128
	Group (I) × T3	1.11	0.47–2.59	0.24	0.407
Stress at work	Intercept	0.00	0.00–0.00		
Low (0) vs. high (1)	Group (I)	1.59	0.52–4.81	0.82	0.207
N = 885	T2	0.95	0.35–2.58	−0.09	0.464
obs = 1795	T3	0.24	0.07–0.84	−2.22	**0.013**
	Group (I) × T2	0.14	0.04–0.51	−2.97	**0.002**
	Group (I) × T3	0.56	0.12–2.72	−0.71	0.238
Sleep (h/day)	Intercept	7.35	7.20–7.51		
N = 877	Group (I)	−0.01	−0.20–0.18	−0.07	0.472
obs = 1765	T2	−0.11	−0.26–0.04	−1.45	0.074
	T3	0.04	−0.14–0.22	0.44	0.330
	Group (I) × T2	0.25	0.06–0.44	2.57	**0.005**
	Group (I) × T3	−0.05	−0.27–0.18	−0.40	0.343

T1 = baseline; T2 = end of cardiac rehabilitation; T3 = at 1 year follow-up; Group (I) = intervention group; log10transf. = log10 transformation; obs = number of observations.
[a]Estimates are unstandardized regression coefficients for continuous outcomes and odds ratios for dichotomous outcomes.
[b]The *t*-values are reported for continuous outcomes and *z*-values for dichotomous outcomes.

Table 5 Linear mixed model analyses of change in secondary outcome measures from T1 to T2 and T3, group effects (control vs. intervention) and interaction effects

Outcome	Predictor	Estimate[a]	CI	t-value	P-value
BMI (kg/m^2)	Intercept	27.20	26.68–27.71		
N = 885	Group (I)	−0.14	−0.78–0.49	−0.45	0.653
obs = 1795	T2	−0.15	−0.31–0.01	−1.79	0.073
	T3	−0.15	−0.34–0.05	−1.50	0.135
	Group (I) × T2	0.15	−0.06–0.35	1.41	0.160
	Group (I) × T3	0.27	0.03–0.51	2.22	**0.027**
Waist circumference	Intercept	100.9	99.39–102.42		
(cm)	Group (I)	−0.92	−2.79–0.94	−0.97	0.333
N = 850	T2	−2.35	−3.61 – −1.08	−3.64	**<0.001**
obs = 1668	T3	−1.72	−3.24 – −0.20	−2.21	**0.027**
	Group (I) × T2	1.96	0.36–3.57	2.4	**0.016**
	Group (I) × T3	0.61	−1.31–2.53	0.62	0.535
Motivation	Intercept	8.19	7.97–8.41		
11-point Likert scale	Group (I)	0.17	−0.11–0.45	1.17	0.122
N = 793	T2	−0.32	−0.63 – −0.01	−2.00	**0.023**
obs = 1600	T3	−0.64	−1.01 – −0.26	−3.34	**0.001**
	Group (I) × T2	0.16	−0.24–0.55	0.78	0.217
	Group (I) × T3	0.15	−0.33–0.63	0.62	0.269
Self-efficacy	Intercept	7.29	7.07–7.52		
11-point Likert scale	Group (I)	0.46	0.17–0.74	3.12	**<0.001**
N = 793	T2	0.53	0.22–0.83	3.39	**<0.001**
obs = 1600	T3	0.22	−0.15–0.59	1.18	0.120
	Group (I) × T2	−0.36	−0.75–0.02	−1.84	**0.033**
	Group (I) × T3	−0.12	−0.60–0.35	−0.5	0.307
Social support	Intercept	7.78	7.50–8.05		
11-point Likert scale	Group (I)	0.28	−0.06–0.63	1.60	0.055
N = 793	T2	0.02	−0.33–0.37	0.12	0.452
obs = 1600	T3	−0.15	−0.58–0.28	−0.69	0.244
	Group (I) × T2	−0.19	−0.64–0.26	−0.84	0.201
	Group (I) × T3	−0.14	−0.69–0.41	−0.50	0.307

T1 = baseline. T2 = end of cardiac rehabilitation; T3 = at 1 year follow-up; Group (I) = intervention group; obs = number of observations.
[a]Estimates are unstandardized regression coefficients.

control group, but these were either negligibly small (−0.15 BMI points for the intervention group, $P = 0.666$) or not sustained over the long-term (waist circumference). Motivation levels slightly declined in both groups, and although self-efficacy improved during CR, this change did not last until follow-up. Social support remained stable over time in both groups. The findings concerning the secondary outcomes are presented in *Table 5*.

Discussion

The present study investigated the added value of the BENEFIT intervention programme, an innovative eHealth platform offering features for monitoring health and behaviour and providing lifestyle interventions and support, on top of taking part in a standard CR programme among patients with CVD. While both the control and intervention groups experienced significant benefits from participating in multidisciplinary comprehensive CR, our findings also suggest that the intervention programme contributed to further improvements in healthy lifestyle behaviours in cardiac patients. Specifically, the intervention group, which received additional support through the eHealth platform showed greater short-term gains with regard to having a healthier diet more rich in vegetables, improved stress management, and more sleep hours. Notably, we also found some preliminary evidence that the intervention increases maintenance of higher physical activity levels lasting up to 1 year. Finally, although patients' confidence in their ability to make the necessary lifestyle changes increased during CR, their motivation, while initially strong, tended to diminish somewhat over time.

At the start of CR patients, in collaboration with a healthcare professional, selected one or two lifestyle areas to focus on for improvement. By far, most patients opted to increase their physical activity levels as a primary means of making lifestyle improvements. One of the most notable outcomes of our study is the sustained, significant and clinically meaningful increase in physical activity among the intervention group, which on average maintained an additional 42 min of exercise per week 1 year post-CR. With the caveat that differences between the intervention and control group just failed to reach significance due to large heterogeneity between participants in each group, it is a remarkable achievement that illustrates the potential of eHealth in facilitating sustained physical activity. This is particularly significant given the challenges of maintaining increased physical activity levels over time in cardiac patients.[7,8] Significant improvements in vegetable intake, stress and sleep were also noted among intervention participants, but only short-term. An 8% increase in vegetable intake represents a modest change and may not be clinically relevant. Sleep duration improved by 15 min, which is below the threshold of 30 min typically associated with substantive improvements in clinical well-being.[31] However, additional analyses revealed that 28% of patients achieved an increase of 30 of more minutes in sleep duration, making this a clinically meaningful outcome for a significant subgroup, further underscoring the holistic benefits of the intervention.[32,33] Finally, the 86% reduction in odds of experiencing work-related stress represents a large, clinically relevant and crucial improvement, as chronic stress can exacerbate cardiovascular issues.[34] In the long-term, these effects were no longer evident. For instance, stress levels related to both home and work decreased in both groups. This reduction may partly reflect a natural recovery process, similar to what has been observed for depression and anxiety following a myocardial infarction.[35,36] To conclude, the intervention produced modest results on most, but not all outcome parameters. It is thus important to balance between the costs and burden of implementing the platform vs. the benefits it provides. Yet it is also important to realize that the observed changes are additional, on top of an intensive, multidisciplinary CR programme during which patients followed weekly personalized fitness sessions and approximately 1–2 group sessions on lifestyle change all guided by healthcare professionals.[20] Many studies on CR actually show a relapse in healthy behaviours over time.[7,8] Interestingly, we did not observe this, even in the control group, despite including patients from diverse socioeconomic backgrounds in the study.

It is also important to realize that once developed, eHealth platforms such as the PHA require relatively low maintenance costs compared with traditional, resource-intensive healthcare services such as CR programmes, which necessitate ongoing personnel costs and infrastructure.[37] An eHealth platform can be disseminated widely to all patients starting CR without significant additional expenses and this scalability makes an eHealth platform particularly cost-effective as it allows for the broad distribution of health resources without a corresponding increase in expenditure. Providing access to an eHealth platform could also alleviate the burden on healthcare facilities by reducing the frequency and necessity of in-person healthcare visits leading to significant cost savings.[38] However, these cost benefits are most substantial when eHealth is used as a partial replacement for usual care instead of an addition to standard care as was the case in this study.[39] Our approach thereby fits in with the movement towards cardiac telerehabilitation,[40] also aiding CVD patients struggling to balance CR with work commitments, by delivering portions of CR care and professional guidance remotely reducing travel costs and travel time for patients.[12,41]

In a preliminary pilot study not reported here, we found that the platform featuring only an automated coaching system received minimal patient engagement, echoing the low participation levels observed in a previous study regarding a comprehensive eHealth programme in CR for CVD patients.[42] It was only after introducing human coaches—who conducted phone calls to discuss lifestyle progress, motivate patients and direct patients to the platform—that we observed a significant increase in platform use. It seems that for our CVD patients, human interaction was pivotal in motivating them to start making lifestyle changes at home using eHealth. With only a few tele-coaching sessions of 15–30 min (the mean number of coaching sessions was 2.4 per person), the personal coaches provided a level of accountability and personalized support that automated systems could not match, thereby proving essential in helping patients making the necessary lifestyle changes at home.[43]

Strengths and limitations of the study

Our multi-centre study, conducted across urban and rural areas in the Netherlands, achieved a high participation rate and included a large, diverse sample of cardiac patients. A comparison of our patients' demographics (i.e. sex, age, and SES) with national data on CVD patients[44] and broader national statistics[45] suggests that our sample is representative of Dutch CVD patients starting CR, supporting the generalizability of our findings within this context However, it is important to acknowledge certain limitations. The study was conducted exclusively in a single high-income country and patients who were either technologically illiterate or non-Dutch speakers were excluded. These factors may limit the applicability of our findings to other countries and subpopulations, particularly those with different socioeconomic or cultural contexts. Another strength of our study is its longitudinal design, with follow-up measurements at 1 year, offering insights into the sustainability of lifestyle changes. Despite these strengths, several limitations should be acknowledged. First, the non-randomized design of the study may have introduced a selection bias, since centres starting in the intervention condition were chosen based on their readiness to implement the intervention. Those selected might already be more motivated, better resourced, and/or more experienced in delivering similar eHealth programmes which could lead to better outcomes regardless of the intervention itself. However, we tried to counter this effect by making sure that all participating centres spent time in both conditions and providing their new patients the according care. Second, more patients were allocated to the intervention than to the control condition due to the fact that, on average, centres spend more time in the intervention than control condition. This was the case because of the need to utilize already hired staff, who were contracted to coach participants in the intervention condition, ensuring they had work during their employment period. This allocating may have introduced several complications, including group comparability issues, whereby the larger intervention group has a more diverse range of patient characteristics at baseline compared with the smaller control group. This imbalance can make it difficult to ensure that any observed differences in outcomes are due to the intervention and not underlying differences between the groups, yet, as can be seen in *Table 2*, the groups were quite comparable at baseline. In addition, differences in sample size may also lead to reduced statistical power to detect a difference between groups. Third, since eHealth usage frequency was not prescribed, all patients in the intervention group were analysed following the intention-to-treat principle. Although limited platform engagement may have diminished the intervention's impact, the average number of usage days and session duration suggest some level of platform engagement, though substantial individual variation was observed. Fourth, our comprehensive lifestyle assessment allowed us to capture a holistic view of participants' lifestyle behaviours. However, all data on lifestyle behaviours were self-reported, which may introduce recall bias and social desirability bias. This reliance on self-reported measures also limits objectivity and may affect the precision of our estimates. Furthermore, our approach to measuring physical activity in minutes per week, while widely used and aligned with European guidelines,[2] does not account for exercise intensity or energy expenditure. Incorporating measures such as MET values, validated food diaries and data from wearable sensors such as smartwatches, could provide more objective and detailed assessments of lifestyle behaviours. Future research should explore these options to enhance the accuracy and specificity of lifestyle behaviour evaluations. Also, we did not specifically assess whether participants left the workforce during follow-up, which could have influenced the change in stress levels. However, return-to-work rates after CR are generally high,[46,47] suggesting that this factor is unlikely to have significantly impacted our findings. Fifth, the intervention produced modest results on most, but not all outcome parameters. It is thus important to balance between the costs and burden of implementing the platform vs. the benefits it provides. In addition, the specific components or working mechanisms responsible for the observed changes were not isolated or investigated in this study. Future research, such as studies utilizing factorial designs,[48] should explore the relative impact of various features of eHealth platforms such as BCTs (i.e. goal setting, daily goal monitoring and feedback)[49] and the role of tele-coaching, to optimize intervention design. Understanding the mechanisms that underlie long-term maintenance of healthy behaviours will be critical in designing effective interventions for chronic disease management.

Conclusion

By extending the support provided in clinical settings into the patient's daily life, eHealth platforms such as the PHA show promise in complementing standard CR care by enabling patients to practice newly learned healthy lifestyle behaviours in their home environment. Observed improvements in physical activity levels, dietary habits, stress and sleep underscore the value of integrating personalized eHealth solutions into CR care. Such a comprehensive and cost-effective approach may also aid in habit formation, making it a valuable addition to traditional healthcare services. This study advocates for the broader use of digital health tools in secondary prevention programmes, offering an approach to advancing cardiovascular health outcomes.

Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology*.

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Author contributions

A.W.M.E., V.R.J., and R.A.K. contributed to the funding acquisition. L.D.B., A.W.M.E., V.R.J., and R.A.K., contributed to the design of the study. L.D.B., R.A.K., I.A.D., and R.V.H.I.J. contributed to the data acquisition; L.D.B., I.A.D., and R.V.H.I.J. contributed to the data analysis and data interpretation; L.D.B. drafted the manuscript; and all authors critically reviewed and revised the manuscript and gave final approval to submit the manuscript for publication.

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Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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