Role of digital health in pulmonary rehabilitation and beyond: shaping the future

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Digital health technologies provide opportunities to improve pulmonary rehabilitation access and uptake in patients with chronic respiratory diseases and support adherence to more active lifestyles, although there are still several challenges to address. https://bit.ly/3VGW4EL

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Abstract

Pulmonary rehabilitation (PR) is a cost-effective intervention with well-known benefits to exercise capacity, symptoms and quality of life in patients with chronic respiratory diseases. Despite the compelling evidence of its benefits, PR implementation is still suboptimal, and maintenance of PR benefits is challenging. To overcome these pitfalls, there has been a growing interest in developing novel models for PR delivery. Digital health is a promising solution, as it has the potential to address some of the most reported barriers to PR uptake and adherence (such as accessibility issues), help maintain the positive results following a PR programme and promote patients' adherence to a more active lifestyle through physical activity (tele)coaching. Despite the accelerated use of digital health to deliver PR during the coronavirus disease 2019 pandemic, there are still several factors that contribute to the resistance to the adoption of digital health, such as the lack of evidence on its effectiveness, low acceptability by patients and healthcare professionals, concerns about implementation and maintenance costs, inequalities in access to the internet and technological devices, and data protection issues. Nevertheless, the trend towards reducing technology costs and the higher availability of digital devices, as well as the greater ease and simplicity of use of devices, enhance the opportunities for future development of digitally enabled PR interventions. This narrative review aims to examine the current evidence on the role of digital health in the context of PR, including strengths and weaknesses, and to determine possible threats and opportunities, as well as areas for future work.

Introduction

Pulmonary rehabilitation (PR) is a cost-effective intervention [1] and a cornerstone of care for individuals with chronic respiratory disease [2]. PR is underpinned by a comprehensive model consisting of a thorough patient assessment followed by a multidisciplinary intervention including, but not limited to, exercise training, education and behaviour change [2]. The main goals of PR are to improve the physical and psychological condition of people with chronic respiratory disease and promote long-term adherence to health-enhancing behaviours [2]. Meeting these goals, PR has shown clinically important benefits in dyspnoea, exercise capacity and health-related quality of life (HRQoL) [3], as well as reduced healthcare use [1].

Despite the compelling evidence of its benefits, PR is still underutilised in the real-world setting, which clearly shows a gap between the international guidelines and the delivery service [2, 4]. The suboptimal PR implementation arises from low uptake and adherence to "traditional" centre-based PR programmes, due to problems including transport issues and geographical distance to PR settings [1]. It is estimated that <2% of eligible patients have access to PR worldwide [5]. In 2015, the American Thoracic Society (ATS) and the European Respiratory Society (ERS) published a policy statement: "Enhancing Implementation, Use and Delivery of Pulmonary Rehabilitation" [1]. Among the recommendations, the ATS/ERS called for "novel PR program models that will make evidence-based PR more accessible and acceptable to patients and payers". In the same year, the ATS/ERS statement was supported by a final Cochrane review concluding that PR is highly effective, but grossly underutilised, calling for novel models of PR delivery [3]. A second remaining challenge in PR is that, in those patients who complete PR, the benefits appear to gradually fade over 6–12 months in the absence of any maintenance strategy [2], which also emphasises the need for maintenance interventions to preserve PR effects over time.

The use of digital health to improve PR delivery is a promising approach as it can address the challenges of centre-based PR programmes by increasing access to PR and/or helping to sustain positive long-term outcomes. Digital technologies are increasingly used and widely available in patients' day-to-day living and in the healthcare systems [6, 7]. The term "digital health" is broadly used in various disciplines such as health informatics, but there is no agreed definition for this term [6]. In the World Health Organization global strategy on digital health 2020–2025 [8], digital health was defined as "the field of knowledge and practice associated with the development and use of digital technologies to improve health". Digital health expands the concept of electronic health (eHealth) to include a wider range of smart and connected devices for digital consumers, and also other uses of digital technologies for health, such as the internet of things or artificial intelligence [8, 9]. In short, digital health can be defined as the use of digital technologies to improve people's health and provide health services [9], which can be done through audio, text messages or video communication, using technologies such as wireless communication and the internet, among others. For the purposes of this review, interventions that consist of telephone calls only are not included in the definition of digital health.

Interest in introducing digital technology into healthcare delivery is not new [1], although the coronavirus disease 2019 (COVID-19) pandemic has spurred strong growth in the use of digital solutions by both patients and healthcare professionals [10]. Specifically, in the context of PR, several programmes had to suspend face-to-face activities to limit patient exposure to the virus and reduce the burden on health systems, increasing the adoption of telerehabilitation services [10, 11]. The great potential of digital health in respiratory care was also highlighted in the presidential summit of the ERS "Digital Respiratory Medicine – Realism *versus* Futurism", held in 2021 [12]. It sought to define the innovations that are realistic for digital respiratory medicine in the "here and now", as well as those that should be considered aspirational and futuristic. Virtual PR was one of the topics for discussion, where the "need to develop engaging digital interventions to support symptom reduction and behaviour change" was emphasised.

Nevertheless, there are still some factors to consider before its widespread dissemination. This narrative review aims to summarise the available evidence on the use of digital health in the context of PR, considering three main goals: as a primary source to deliver PR; as a tool to promote patients' adherence to health-enhancing behaviours, specifically physical activity; and as a maintenance strategy to sustain PR benefits in the long term. It also examines the micro (individual level) and macro (system level) factors that need to be addressed to ensure that digital technologies are deployed successfully and meaningfully.

Use of digital health in PR

Digital health as a primary source of PR delivery

Digital delivery models of PR have the potential to address many of the patient-related and system-related barriers for PR programmes, including improvements to access (*e.g.* reducing geographical restrictions using remotely delivered models), uptake (allowing patient preference and reducing barriers related to travel and disability) and completion (decreasing the burden of attendance, enabling continuing participation despite fluctuations in symptoms and functional status) [13]. In addition to digital delivery of PR, there is now the opportunity to incorporate wearables (*e.g.* for physical activity promotion, heart rate monitoring, spirometry measures) for remote monitoring. Digital models also offer the opportunity to embed innovations in education delivery and behavioural change in PR. Lastly, by definition, PR is a personalised intervention and digital delivery modes can complement this principle, for example by allowing flexibility of intervention components [14]. Ultimately, the goal must be to provide clinicians and providers with multiple options for effective PR delivery models. This may allow patients to be offered the programme in which they are most likely to succeed, which can vary according to factors such as the disease stage, comorbidities, psychosocial features, digital literacy, previous PR experience and patient preference.

Evidence on the use of digital health as a source of PR delivery was provided in a Cochrane review in 2021 [15]. This review included 15 studies of which six were randomised controlled trials (RCTs) delivering four different modes of digital PR requiring internet [16–21]. Findings across the multiple modes of digital delivery suggest that digitally delivered PR and outpatient PR are equally safe and produce similar results on functional capacity, symptoms, HRQoL and hospitalisation rates ($p>0.05$) (figure 1 and supplementary table S1), whereas completion rates are higher in the digital PR groups compared to participants in outpatient PR settings (93% *versus* 70%) [15].

Since the publication of the Cochrane review, three new RCTs delivering digital PR requiring internet access have been published [22–24]: two through mobile/tablet apps plus individualised telephone/chat support [22, 23] and one through in-group supervised videoconferences [24]. One of the studies involved participants with interstitial lung disease (ILD) solely [22]; another included patients with different chronic respiratory diseases, specifically patients with COPD (69%), ILD (7%), sarcoidosis (15%) and asthma (9%) [24]; and the last study concerned only participants with COPD [23]. All three RCT studies stated “no adverse event recorded”, thus finding safety similar to the results published in the Cochrane review (supplementary table S1) [22–24].

Besides obvious differences in modes, content and duration, a glance over the presented studies uncover that the level of the participants’ technical skills was sparsely defined (table 1). Consequently, this indicates that the trial participants were selected and likely had a positive attitude towards digitally delivered PR and felt confident in their own technical capabilities beforehand. Knowledge of attitude and capability towards digital delivery of PR within the group of patients to whom these digital solutions are intended for needs to be uncovered to move forward. This is likely to vary within regional, cultural, economic and infrastructural contexts across the world [1, 25].

Description of the digitally delivered PR programmes varied from limited to detailed protocols. Table 1 provides an overview of the digital models requiring internet access. Three studies used a group-based videoconference platform [18, 21, 24], whereas the remaining digital interventions included various technologies delivered to individual patients: website with weekly telephone support [16, 17]; website only [20]; and a mobile/tablet application with weekly telephone/chat support [19, 22, 23]. The session frequency and duration of the digital PR programme were very heterogeneous, ranging from two to seven sessions per week, and from 6 weeks to 9 months (table 1).

Seven trials provided exercise equipment including bicycle ergometer [21, 24], free weights [17, 18], step box [18, 22, 23] and pedometer [20]. Six trials also provided mandatory or tailored exercise videos on websites [16, 17, 20] or a tablet [19, 22, 23]. Aerobic exercise included a walking or ergometer cycling programme, step boxes and/or body calisthenics. Resistance training with free weights was used in two trials [17, 18], and another seven used water bottles, TheraBands or body weight [16, 19–24]. All programmes included an exercise diary.

Provision of formal education was heterogeneous and included group-based, structured, live sessions *via* video or unsupervised web-based modules. Two studies did not provide any formal educative programme or written material [19, 21], which does not fully meet the accepted definition of PR [2].

While existing research provides convincing data that it is possible to deliver remote exercise training, education and self-management, with similar outcomes to traditional centre-based PR, all the existing clinical trials have included an in-clinic assessment module prior to programme commencement, and thus they do not provide evidence or insight for remote assessments, *i.e.* which assessment tests are feasible with minimal space requirement with or without remote monitoring [15, 22–24]. Home-based assessment, either supervised or remotely administered and monitored, is potentially relevant for barrier removal in PR uptake and enrolment while maintaining the ability to tailor and evaluate an intervention programme.

More recently, during the COVID-19 pandemic, Holland *et al*. [26] published a rapid review to uncover potential feasible, reliable, valid and responsive home-based supervised or remotely administered assessment tests [26]. Home-based assessment tests administered and supervised by a healthcare professional included the five-times sit-to-stand (STS), 30-s STS, 1-min STS, Timed Up and Go and five various step tests. From the included studies, only one investigated and compared a remotely administered 3-min step test (3MST) with an in-person supervised 3MST in adults with cystic fibrosis [27]. All included assessment tests presented acceptable clinimetric data, thus indicating that they are likely able to measure and detect change over time. However, none of the home-based assessment tests were validated for exercise prescription and safety measures, that are commonly extracted from the 6-min walk test, the

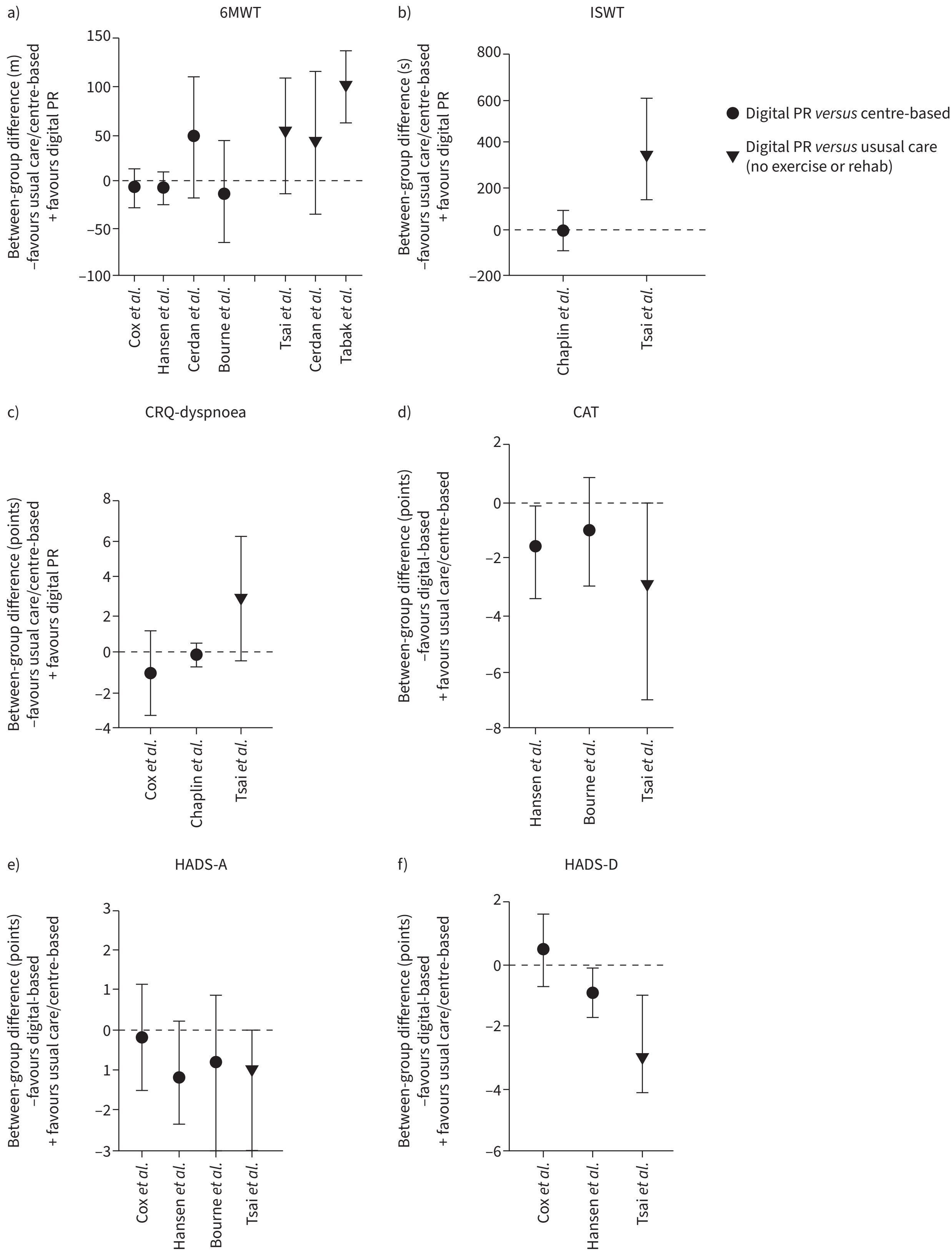

FIGURE 1 Between-group differences in the outcome measures at the end of digital pulmonary rehabilitation (PR), compared to centre-based PR or usual care. a,b) Differences in exercise tolerance: a) 6-min walk test (6MWT); b) incremental shuttle walk test (ISWT); c–f) differences in symptoms: c) Chronic Respiratory Questionnaire (CRQ) dyspnoea; d) COPD Assessment Test (CAT); e) Hospital Anxiety and Depression Scale – Anxiety (HADS-A); f) Hospital Anxiety and Depression Scale – Depression (HADS-D).

TABLE 1 Overview of digital delivery modes and content of pulmonary rehabilitation (PR)

	Videoconference, supervised, in groups	Mobile/tablet application plus telephone/chat support, individualised	Website, and possible query *via* website or phone/mail support (chat), individualised	Website with no support, individualised
Studies	Cox, 2022 [24] (n=142) Hansen, 2020 [18] (n=134) Tsai, 2017 [21] (n=36)	Cerdán-de-las-Heras, 2021 [22] (n=29) Cerdán-de-las-Heras, 2021 [23] (n=54) Kwon, 2018 [19] (n=58)	Bourne, 2017 [16] (n=90) Chaplin, 2017 [17] (n=103)	Tabak, 2014 [20] (n=30)
Programme format	Primary PR 2–3 sessions per week 30–60 min per session 8–10 weeks Education themes [18, 24]	Primary PR 3–5 sessions per week 10–30 min per session 7–8 weeks Self-management web-modules [22, 23]	Primary PR 3–7 sessions per week Length of session not stated 6–8 weeks Self-management web-modules	Primary PR 7 sessions per week Length of session not stated 9 months Self-management web-modules
Technical skills	No technical level required [18] Required technical level [21] Not stated [24]	Knowledge of android OS	Required technical level	Required technical level
Exercise content: aerobic training	Stepping Major muscle group exercises Indoor cycling Walking programme	Walking programme Stepping	Calisthenics Walking programme	Calisthenics Pedometer
Exercise content: resistance training	Major muscle groups for upper and lower body and limbs	Upper- and lower-limb exercises	Upper- and lower-limb exercises	Upper- and lower-limb exercises
Equipment	Stationary bike Body weight Dumbbells Step box	Water bottles Body weight TheraBand Step box	Water bottles Body weight Dumbbells	Water bottles Body weight Pedometer Video-illustrated exercises
Monitoring during programme	Pulse oximeter Exercise diary BORG-CR10 Repetitions	Pulse oximeter	Registry of web-usage Milestone programme visualisation Exercise diary Visual analogue scale for intensity/difficulty BORG-CR10	Accelerometer-based activity sensor
In-clinic assessments and outcomes	6MWD 30secSTS ISWT ESWT CAT HADS EQ-5D CCQ CRQ PRAISE PA (steps per day) Adverse events Admission Mortality	6MWD CRQ SGRQ GAD-7 PA	6MWD ISWT ESWT CAT HADS SGRQ CRQ PRAISE EQ5D-5L BCKQ mMRC Adverse events	6MWD CCQ MFI-20 EQ-5D MRC PA ED visit LOS

OS: operating system; CR: category ratio; 6MWD: 6-min walk distance; 30secSTS: 30-s sit-to-stand; ISWT: incremental shuttle walk test; ESWT: endurance shuttle walk test; CAT: COPD Assessment Test; HADS: Hospital Anxiety and Depression Scale; EQ-5D: EuroQol 5-Dimension; CCQ: Clinical COPD Questionnaire; CRQ: Chronic Respiratory Questionnaire; PRAISE: PR Adapted Index of Self-Efficacy; PA: physical activity (steps per day); SGRQ: St George's Respiratory Questionnaire; GAD-7: General Anxiety Disorder-7; BCKQ: Bristol COPD Knowledge Questionnaire; mMRC: modified Medical Research Council dyspnoea score; MFI-20: Multidimensional Fatigue Inventory; ED: emergency department; LOS: length of stay.

shuttle walk test and the cardiopulmonary exercise assessment test prior to PR commencement [26]. Summarising the current literature on home-based assessment points out a major need for research, evidence and knowledge on novel remote assessment methods complementary to digital delivery methods. Thus, in-clinic patient assessment seems to be the preferable and safest option whenever possible, yet there must be a delicate balance not to exclude relevant participants who live remotely and/or lack the energy and resources to attend in-clinic assessment before commencing a digitally delivered PR programme. Consequently, home-based assessment tests administered and supervised by a healthcare professional might be considered a second-choice option or performed in combination with in-clinic visits.

Ultimately, the success of all digital delivery models of PR will be judged on whether the essential PR components are delivered and on whether the expected patient outcomes are achieved, including improved exercise capacity, reduced dyspnoea, enhanced HRQoL and reduced hospital admissions. From current evidence, digital delivery appears to be a safe and a potential alternative to conventional PR [1, 25]. However, the existing heterogeneity in study samples, delivery method, supervision and content published to date makes it difficult to reach a reasonable evidence-based consensus. This calls for consensus around standardised digital models to enable evidence-based implementation. Essentially, future digital PR programme designs must include specific considerations regarding the country-infrastructural condition, delivery form and content and definition of technical skills of the target population, particularly if these programmes are to be offered to people who live remotely and/or lack the energy and resources to attend a conventional PR programme. Doing so will help bring PR providers one step closer to sorting out which patients are best suited to enrol, complete and benefit from a digitally delivered PR programme, and which type of digital delivery mode to use.

Furthermore, quality assurance is important to ensure that any digital delivery model of PR provides optimal outcomes for patients and health services. Lastly, cost-effectiveness studies are missing to evaluate the short- and long-term efficacy and cost-effectiveness of digitally delivered PR programmes.

Digital health used in physical activity telecoaching as an add-on to PR

Based on overwhelming evidence, being physically active is known to be important for patients with chronic respiratory disease. A higher physical activity has been related to important clinical outcomes, such as HRQoL, exacerbation risk and mortality [28, 29]. Therefore, physical activity management is a recommended therapy for all patients with COPD [30] and achieving sufficient physical activity levels should be one of the targets of PR [2].

As a concept, physical activity is distinct from exercise capacity [28] and it is known that only providing a supervised exercise training programme will not result in an important increase in physical activity. Based on the definition of PR, which includes exercise training, but also education and behaviour change [2], increasing the patients' physical activity level is an important target of PR. However, its influence on patients' adoption of active lifestyles is modest if present at all [31]. This effect has been estimated as 350 steps·day^{-1} based on the available literature [32]. Hence, when aiming to increase physical activity, additional interventions including behavioural strategies (physical activity coaching) are the option of choice [33].

These physical activity coaching interventions specifically aim to increase the amount of physical activity. Because typically the intensity of physical activity is not specified and the intervention is provided without direct supervision, the intervention targets physical activity at the lower intensities. Most coaching programmes are focused on walking behaviour and include the increase of total number of steps per day as the incentive. Important components in these programmes are self-monitoring (*e.g.* by using a step counter), receiving feedback on the behaviour (*e.g.* during face-to-face contact with a coach) and the use of adaptive goal setting (*e.g.* discussed during face-to-face contact and/or written in a diary). When using technology-mediated interventions ("telecoaching"), these components are integrated into a system using communication from a distance (*e.g.* online platform, smartphone application) [33]. The step counter needs to transfer data to the coach or coaching platform; feedback and goal setting are delivered *via* the coaching platform. Thus, the use of digital health in physical activity coaching programmes allows patients to be reached from a distance and enables regular interaction with patients without increasing the burden on both the coach and the patient [34].

Most research about the effectiveness of physical activity coaching interventions is available in patients with COPD, as a standalone intervention outside a PR setting. Physical activity (tele)coaching interventions have been successful to increase physical activity in these studies (figure 2a) [35–43]; achieving the minimal important difference in most studies (600–1100 steps·day^{-1}) [44]. Both coaching

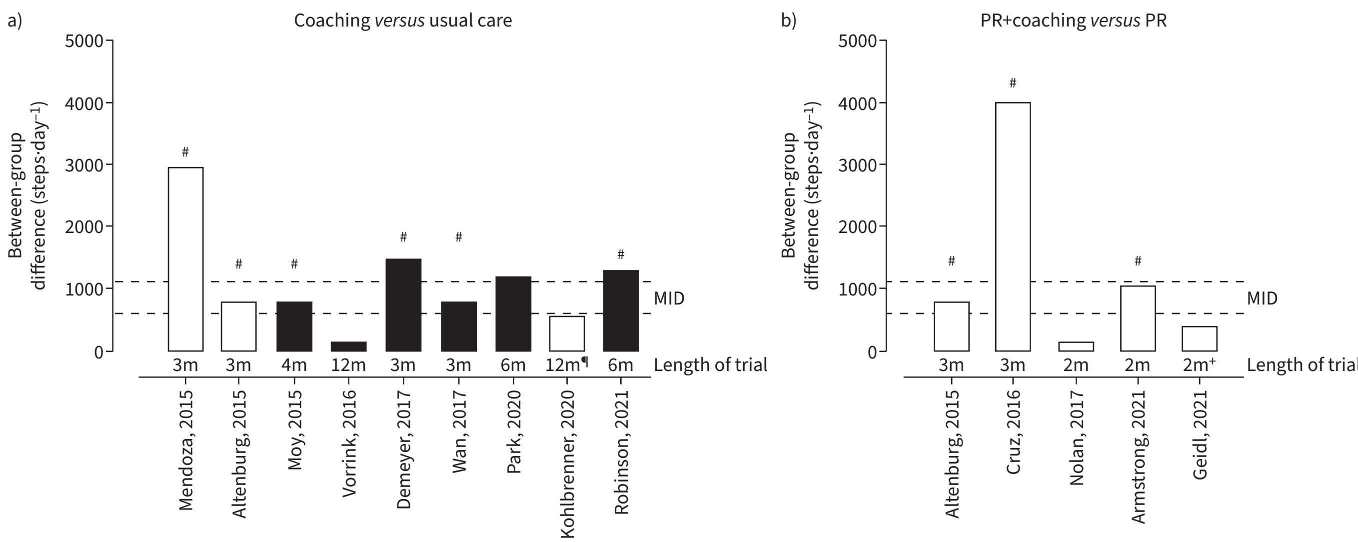

FIGURE 2 The effectiveness of physical activity (tele)coaching. PR: pulmonary rehabilitation; MID: minimal important difference (600–1100 steps·day^{-1}) [44]; m: months. #: statistically significant between-group difference; ¶: 3-month intervention followed by 9 months of follow-up; +: 9-week coaching intervention, of which the first 3 weeks were combined with an intensive PR programme.

and telecoaching interventions have been tested with comparable effects. However, it should be noted that the intervention effect was mostly described at the short-term only (3–4 months) and long-term effects are uncertain [35]. In patients experiencing an exacerbation, physical activity coaching during 1 month after hospital discharge did not have additional effect on physical activity on top of usual care (change: intervention 984±1208 steps·day^{-1}, control 1013±1275 steps·day^{-1}; interaction effect p>0.05); however, this is only based on one pilot study [45]. It is important to notice that these effective physical activity coaching interventions did not present clinically relevant exercise capacity improvements, with effects ranging between −4 m and 19 m when compared to usual care [35, 36, 38, 41–43].

The question remains whether such physical activity (tele)coaching interventions can be combined effectively with a PR programme in order to obtain the desired increase in patients' physical activity levels [2]. Figure 2b summarises the effectiveness of (tele)coaching interventions added to a PR programme compared to a group of patients who only received PR [35, 46–49]. All the included interventions used the aforementioned behavioural strategies (continuous self-monitoring, receiving feedback and goal setting). Of note, two studies not including self-monitoring feedback (*e.g.* by a step counter) in the behavioural intervention on top of PR did not show an additional effect of the physical activity intervention (between-group difference 300–500 steps·day^{-1} at the end of the PR programme; p>0.05 in both) [50, 51]. Remarkably, none of the interventions added to PR included telecommunication (figure 2b). This can potentially be explained by the frequent face-to-face contacts between patient and coaches as part of the supervised exercise training programme, making the use of technology in the communication less needed. However, because more and more PR programmes are provided remotely using telerehabilitation, it is likely that technology will be integrated in add-on interventions focusing on physical activity in the future.

Furthermore, future work will need to identify the best timing to start such physical activity coaching interventions when added to PR. A higher baseline exercise capacity and lower symptom burden have been associated to a larger increase in physical activity as result of a smartphone-based telecoaching intervention [36]. Because PR is known to result in an increased exercise capacity and an improved symptom burden [3], it might be more effective to start physical activity coaching at the final stage of a PR programme. A direct estimate of costs related to adding a physical activity coaching intervention is needed to test cost-effectiveness. One study estimated the costs for the equipment of a coaching intervention including an activity monitor (ranging between USD 35 and USD 200) and access to a website (USD 215 for a WiFi-enabled iPod) [52]. Costs for the healthcare professionals providing the coaching were not included. However, the latter seems reasonable considering the limited contact between patients and healthcare professionals during a 3-month semi-automated coaching intervention [34]. Finally, most of the literature on physical activity coaching interventions is solely based on patients with COPD. However, maintaining an active lifestyle has also been shown to be important for other respiratory patient populations such as patients with asthma, ILD and lung cancer and patients receiving a lung transplant. Two studies showed the effectiveness of interventions aiming to increase physical activity in clinically stable adult patients with asthma [53, 54]. In more detail, both studies investigated a physical activity coaching intervention including self-monitoring by a step counter and goal setting. In the study by Freitas *et al.* [54], patients received a weekly face-to-face counselling session, compared to a weekly phone call in the study by Coelho *et al.* [53]. Patients received a new target weekly [54] or biweekly [53]. Both studies showed a significant and large increase in daily step count after 8 weeks (mean between-group difference: 3605 steps·day^{-1} [54]) or 12 weeks (adjusted mean difference: 2488 steps·day^{-1} [53]). However, when patients in the latter study were followed-up, these differences were not sustained 24–28 weeks after randomisation.

To the best of our knowledge, no studies on physical activity coaching are available in other patient populations with chronic respiratory disease. Future research will need to investigate whether the results found in COPD could be translated to these other populations.

Digital health as a post-PR resource: maintenance of the effects

One of the main challenges of PR is the maintenance of its effects. Previous research has shown that the benefits of PR tend to diminish over 6–12 months after rehabilitation, unless patients continue to exercise [2, 55]. One previous study showed that 70% of the patients have difficulty in maintaining endurance activities 3 months after PR, and this difficulty is influenced by disease-related symptoms and functional limitations in some patients, while others report barriers to exercise related to costs, family and exercise facilities [56]. Lack of self-efficacy, motivation and fear of exercise without supervision are other common reasons for patients not to engage in exercise/physical activity behaviours at home [57, 58]. Repeating PR at regular intervals can avoid the deterioration in exercise capacity, dyspnoea and HRQoL [55]. However, it may not be feasible in the long-term for many reasons, including limited healthcare resources, the already low accessibility of PR [59] and the rising prevalence of chronic respiratory diseases [60].

This has led to interest in developing maintenance programmes to sustain the gains achieved with PR [61]. The core component of these programmes is usually exercise training, and they can also include self-management education and support [61, 62]. When supervised, the frequency of supervised sessions is usually inferior to the initial PR programme, since it is assumed that patients have already developed skills during the PR programme to self-manage their health independently and, therefore, they need less supervision [61]. Although the optimal means to deliver these maintenance programmes are still unclear [61], digitally delivered home-based maintenance programmes may be a solution, as they can enhance patient engagement in self-management, for example by facilitating long-term integration of exercise routines into daily life, and improve patient–clinician communication [62, 63]. This is an emerging area of research and evidence is still of low certainty due to the reduced number of studies [15, 61].

To the best of our knowledge, there are only three RCTs implementing digital technology-supported home-based maintenance programmes; two studies from Spain [64, 65] and one from Greece [63], all conducted in COPD. In these studies, maintenance programmes were preceded by an 8-week PR programme including exercise training and education, and were implemented over a period of 10 [65] to 12 [63, 64] months. Studies were focused on different outcomes, although all included at least one outcome measure of exercise capacity and HRQoL. A description of the RCTs is provided in supplementary table S2.

The study by Vasilopoulou *et al.* [63] compared a home-based maintenance telerehabilitation programme with a hospital-based programme, both implemented after PR, and with usual care [63]. The authors found that telerehabilitation was equally as effective as hospital-based rehabilitation in maintaining the improvements achieved with the initial PR programme in exercise capacity, symptoms, physical activity and HRQoL, and both interventions led to a significantly lower rate of acute exacerbations (home-based tele-PR: incidence rate ratio (IRR) 0.517, 95% CI 0.389–0.687, hospital-based PR: IRR 0.635, 95% CI 0.473–0.853; $p<0.05$) and hospitalisations for acute exacerbations (home-based tele-PR: IRR 0.189, 95% CI 0.100–0.358, hospital-based PR: IRR 0.375, 95% CI 0.207–0.681; $p<0.05$). Furthermore, the telerehabilitation programme (but not the hospital-based programme) was an independent predictor of emergency department visits (home-based tele-PR: IRR 0.116, 95% CI 0.072–0.185; $p<0.001$).

Adherence to the telerehabilitation programme was 93.5%, showing that this type of intervention is feasible. Both telerehabilitation and hospital-based interventions showed better results in exercise capacity, symptoms, physical activity and HRQoL compared to usual care ($p<0.05$), which was already expected as, in this study, the usual-care group did not receive initial PR [63]. A previous Cochrane review concluded that additional RCTs comparing (initial) PR to usual care are no longer required in COPD, as the benefits of PR are well documented and support its implementation as a cornerstone of COPD management [3]. However, PR is not yet a common service provided to suitable patients in many countries [1, 59], including in Greece, where the study was conducted [63].

The other two studies compared a maintenance telerehabilitation programme with advice to keep physically active (not supervised) [64, 65]. These studies found that telerehabilitation programmes did not significantly or clinically improve patients' exercise capacity and HRQoL, although they were feasible, safe [64] and well accepted by most patients [65].

The small number of studies and the heterogeneity of methodologies hinder conclusions about the role of digital health in maintaining PR effects. Some characteristics were common among studies, such as the inclusion of an individualised exercise training component, a mobile interface for patients to record data and/or receive feedback, pre- and/or post-exercise remote monitoring and a web-based platform for healthcare professionals to review the data on a regular basis and respond appropriately, if required. Nevertheless, studies diverged in the type of technology employed and its features, components of the maintenance intervention (*e.g.* exercise training, education, monitoring), equipment required for the exercise training component, type/timing of training provided on how to use the technology and frequency of contact with healthcare professionals (not reported in two studies [64, 65]). Previous research has shown that professional support after PR is highly valued by patients to enhance their motivation to remain physically active [57, 58]; therefore, it should be a component to consider in future studies. The initial PR programme may also play a role in the success of these interventions, as patients need to achieve sufficient gains during PR to be sustained with the maintenance programme [62]. From the studies presented above, only one clearly showed clinical and/or significant improvements in symptoms, exercise capacity and HRQoL after the initial PR [63].

Findings highlight the need for future research to identify the best mode(s) of implementing digital health in maintenance programmes and to understand its value as a long-term strategy to sustain PR benefits. There are still some questions and areas for future work. Firstly, it would be important to assess the cost-effectiveness of maintenance interventions to justify the resources involved [15]. In their study, Vasilopoulou *et al.* [63] estimated the total cost per patient of the 12-month maintenance telerehabilitation programme including the equipment, development of the digital platform, use of 3G network and cost of personnel (EUR 1800). The authors concluded that it was equivalent to ∼60% of the estimated total cost saved by reducing the frequency of acute exacerbations and ∼40% of the estimated cost for 1 year of hospital-based outpatient maintenance rehabilitation sessions [63]. Nevertheless, in this study, no specialised equipment for home-based exercise training was required [63], while in the study by Galdiz *et al.* [64], an exercise bicycle and dumbbells were provided for patients to continue exercising at the same intensity as in the initial PR. Secondly, it would be important to determine the "best candidates" for a home-based telerehabilitation maintenance programme. Although the aforementioned RCTs showed good adherence rates (except for one study [64]: 60%), patients often identify barriers and difficulties when using digital technology which should be taken into account when defining the maintenance strategy (this topic is addressed in the next section). Finally, the ability of these maintenance programmes to promote health-enhancing behaviour changes after their completion, including the adoption of regular exercise training autonomously, is still unknown [66], as none of the studies assessed the short- or long-term effects of the maintenance programme.

Patient and professional perspectives of digital health (individual level)

To maximise the potential of digitally enabled PR, achieving successful user-adoption is critical. However, poor retention rates related to user-experience issues are commonly cited as negatively impacting user-adoption for respiratory digital interventions [67–69]. To help address these shortcomings, this section aims to provide healthcare professionals interested or involved in PR digital transformation with a brief overview of user and design considerations to support the development of fit-for-purpose interventions. Firstly, let us consider the salient patient and healthcare professional user-adoption barriers and facilitators facing digital interventions in the respiratory context.

Barriers and facilitators to adoption: patient perspective

There are still many challenges and unanswered questions regarding patient and healthcare professional adoption of digitally enabled PR [11, 70]. However, recent work has begun to explore the implementation and adoption needs of patients and healthcare professionals for digital health in the management of COPD, much of which is relevant to the design of digital PR interventions [71]. This research suggests that primary barriers facing respiratory patients are a lack of perceived usefulness, digital literacy and illness perception [71].

Perceived usefulness refers to the degree to which a person believes the digital health intervention could improve or enhance their ability to manage their condition and is a core determinant of sustained engagement [72]. For example, patients may feel that a digital approach will impinge on the benefits of face-to-face contacts, as they may no longer have physical access to healthcare professionals for support and direction [71, 73]. Interestingly, research has found that patients with COPD perceive several potential benefits arising from digital approaches to support self-management, which suggests there are cohorts of patients already primed to adopt them [74].

Digital literacy refers to the person's ability to search, acquire, comprehend and appraise health information from digital technologies with the goal of improving their quality of life [75]. Research has found that patients feel they would disengage from technology if they were unable to understand its use and content within an intervention [71]. Similarly, research with respiratory healthcare professionals highlighted their concerns regarding low levels of health literacy among patients [76]. They felt that the added burden of patients needing to understand a digital intervention on top of their already complex treatment plans could lead to disengagement [76].

A patient's illness perception and social context have also been highlighted as barriers to adopting digital interventions [71]. For example, a patient may feel their symptoms are too severe at present to take on the added workload of a digital component or, if patients live on their own, they may not feel confident to use the technology as they lack support to help them navigate the intervention.

Research has begun to investigate facilitators to support respiratory patients with the adoption of digital interventions [71, 76]. This work highlighted that both healthcare professionals and patients were eager to avoid the assumption that all patients are suitable for a digitally enabled treatment plan. Instead, a patient-centric approach should be considered to evaluate patient characteristics, such as physical and mental wellbeing, levels of health literacy and self-efficacy and psychosocial status to determine their readiness to adopt the technology. This research found that patients with existing digital skills, such as experience using a laptop or smartphone, would find it easier to adopt digital health interventions. Assessing the maturity of the technical infrastructure of the patient's home, such as the presence of a stable internet connection and their access to required technologies, such as laptop computers or smartphones, has also been identified as a potential facilitator for patients' adoption of digital interventions [11, 18]. Shared decision-making and concordance approaches were favoured as mechanisms for supporting patients to adopt digital interventions. For instance, when introducing a patient to a digital intervention for the first time, discussing the intentions, concerns and expectations regarding the intervention was perceived as a valuable approach for determining whether to use the technology [76].

Barriers and facilitators to adoption: the healthcare professional perspective

Research suggests that healthcare professionals perceive the lack of evidence demonstrating the effectiveness of digital health interventions on patient outcomes as a salient barrier to them adopting this model of care [76]. Although digitally enabled PR has accelerated during the pandemic, there is agreement on the need for large-scale, longitudinal studies to demonstrate the cost and clinical effectiveness of digitally enabled PR [70, 77]. For example, cardiac telerehabilitation has developed a strong evidence-base, including a Cochrane review demonstrating that this model reduces re-hospitalisations and is equally cost-effective as standard rehabilitation programmes [78, 79]. As a result, cardiac telerehabilitation is considered an important secondary cardiovascular prevention component by the European Association of Preventive Cardiology and European Society of Cardiology [79]. In response, the Netherlands made a recent addendum to the Dutch multidisciplinary cardiac rehabilitation guidelines to incorporate telerehabilitation, the first country worldwide to do so [79].

Training and resource barriers are also commonly cited by healthcare professionals [73, 76]. Research evaluating healthcare professionals' perspectives regarding a virtual PR programme found that more preparation and training time is needed to empower them to identify and address technical issues when they arise [73]. For example, internet connection issues, such as audio-lag, were common and caused problems for patients receiving information in real-time, but healthcare professionals felt this could have been avoided with training [73]. Added staffing resources during the early stages of the programme were also emphasised as healthcare professionals felt they required an extra person to help with the administration and technical aspects as they increased their competencies in managing a virtual PR session [73].

Design considerations: aim to understand and involve end-users

Researchers have argued that user-adoption issues may occur from an unwillingness to involve key stakeholders, such as patients and healthcare professionals, in the design process [68, 80]. Without their involvement, solutions are often biased by assumptions of what user needs are. Subsequently, if these assumptions are inaccurate, users are less likely to perceive the intervention as useful, and user-adoption issues, such as those outlined earlier, are probable [81, 82]. To address these issues, user-centric design methods, such as human-centred design and design thinking, are increasingly being accepted as the gold standard when developing digital health interventions [83–87]. Relevant takeaways from user-centric design methods include the following.

- Consider user-centred research as the starting point of the design process. User-centred research primarily employs qualitative methodologies (*e.g.* interviews, observations) to garner a deeper understanding of end-user behaviour and needs to inform the development of relevant use-cases and user-requirements. It is associated with smoother implementation, lower attrition rates, increased user-experience and sustained engagement [88–91].
- Consider an iterative, co-design approach. The aim of this approach is to garner feedback early and often from users so that the design can be iterated to ensure the creation of a solution that makes sense and is perceived as useful and useable to them [92, 93]. For example, include patients and healthcare professionals in brainstorming/ideation sessions: the aim is to leverage the knowledge from stakeholders to ideate potential solutions; gain feedback on low-fidelity (*i.e.* early or initial) concepts from end-users, which may be as simple as sharing sketches of potential solutions; and test high-fidelity (*i.e.* close to final version) prototypes, for instance, testing clickable/functional prototypes for usability.

Technical, privacy and regulatory issues in digital health (system level)

In addition to the need for successful user adoption of digital health technologies, there are potential challenges regarding technical, regulatory and privacy issues that need to be considered when developing and implementing digitally enabled PR interventions.

Technology and internet access

Digital technologies offer the potential to overcome barriers to accessing PR services (such as travel, transport and location), by increasing coverage in more isolated areas and enabling closer monitoring of patients [1, 25]. However, they may also aggravate the existing access disparities, due to the need for digital technology and appropriate infrastructures, including internet access [7, 94]. Recent studies have found that, while digital technologies are ubiquitous in daily lives of most patients with chronic respiratory diseases, particularly mobile phones [95–97], only a limited number of patients have access to the internet and/or are confident in using it [95–98], which may create a problem of inequitable access to intervention enrolment. These studies were conducted in high-income countries, and the scenario may be even worse in low- and middle-income countries.

Even though internet acceptance has accelerated worldwide during the COVID-19 pandemic, rising from 54% in 2019 to 63% in 2021, nearly 3 billion people remain offline, 96% of whom live in developing countries [99]. Furthermore, the percentage of internet users in urban areas is twice higher than in rural areas [99] and, in patients with chronic respiratory disease, lack of internet access was related to an older age [96], lower education [95], lower income and the presence of a mobility-related disease [98]. This raises a potential problem of inclusion, as individuals who could benefit most from digital technologies are the least likely to access them.

The growing availability of the internet and mobile phones and increasing efforts to improve in digital literacy [8], including in the elderly population [100], may help tackle this issue [7]. However, it is acknowledged that digital interventions are not a "one size fits all" approach [25], and there is a need to better understand the characteristics of patients who can benefit most from digital health. Digital home-based programmes may be more suitable for patients with good connectivity and digital self-efficacy, while centre-based programmes may be a better alternative for those who lack the resources or are uncomfortable using technology [94]. The assessment of patients' suitability for digitally enabled interventions may be facilitated by the use of tools such as the eight-item Dutch Blended Physiotherapy Checklist [101]. This checklist consists of five items with prerequisite patient characteristics for being suitable for this model of care, including motivation, safety, equipment, digital skills and health literacy, and three items focused on characteristics that can influence the appropriate amount of therapeutic guidance alongside a digital technology, related to self-management, time and financial factors [101].

Data protection and technical issues

Another concern is related to patient privacy and data protection [102]. Expanding the use of digital technologies to deliver PR services and healthcare has been accompanied by a substantial increase in connectivity and exposure, for example by sharing personal data (*i.e.* information relating to an identified or identifiable person [103]) and/or sensitive data (*e.g.* health-related data), which may be variable depending on the technology used (*e.g.* videoconferencing, websites, mobile apps, connected devices), but is present in all [102, 104]. Health institutions are known to be among the most vulnerable and targeted systems in terms of cyberattacks [104], even more so during the COVID-19 pandemic [102], which can ultimately lead to suboptimal care or harm to people. Therefore, digital health technologies and software systems, particularly when concerning the use of mobile and web-based tools, must comply with regulatory and ethical principles to ensure data protection and patient privacy and safety, thus preventing health information security breaches. This should be conducted from the early stages of technology design [102]. There are several national and international privacy protection laws, regulations and best practices that can guide this process; some of these resources are provided in supplementary table S3.

Other common challenges in the use of digital technologies concern technical issues (*e.g.* development of the system architecture, redundancy in case of system failure, software and/or hardware updating), clinical validation of the technology employed (*e.g.* device accuracy and calibration to monitor physiological parameters), usability assessment, patient consent for data collection and transfer, and the anticipated impact of the technological solution on the outcome(s) of interest [7, 105]. These challenges highlight the complexity of designing and implementing interventions with digital technologies and the need for the well-coordinated work of a multidisciplinary team, including professionals from the areas of healthcare, informatics, cybersecurity and design to address clinical and technical issues [106]. Stakeholders and policy makers should also be involved to ensure that the digital solution is meaningful but also ethical, safe, valid, reliable and sustainable [8]. Furthermore, it is important to provide training and raise awareness of all stakeholders about digital literacy and security best practices to facilitate adherence [102, 107].

Reimbursement of digitally enabled PR

The use of digital health as a novel form of PR delivery will need to be endorsed by healthcare payers. Recent ERS/ATS statements highlight that payers can be relatively slow to adopt new concepts, and reimbursement issues are present even in traditional (centre-based) PR [1, 101, 108]. This reality was temporarily altered in some countries due to the need for social distancing imposed during the COVID-19 pandemic, through the implementation of reimbursement policies that allowed the spread of remote delivery of PR using technologies instead of face-to-face clinical visits [11]. However, it is still uncertain how this situation will evolve in the long run. Regardless of where PR is delivered (centre-based or digital-based), one of the main reasons funding and reimbursement remains a challenge is the inadequate awareness among payers of the clinical effectiveness and cost-effectiveness of PR [1]. Therefore, efforts should be made to improve communication about the benefits, costs and value of PR to policymakers and payers to support the adoption of PR in healthcare systems as a "standard of care" component for patients with chronic respiratory diseases [1].

Furthermore, as mentioned previously, the success of any PR should be judged on whether the key components are delivered and whether expected patient outcomes are achieved (*i.e.* improved exercise capacity, symptoms, HRQOL, reduced hospitalisations) [25]. An official ATS report published in 2021 identified 13 essential components of PR that should be delivered in any PR model, including digitally enabled PR, which comprises aspects related to patient assessment, programme content, delivery method and quality assurance [25]. Still, before digitally enabled PR models can be successfully integrated into the healthcare systems and be widely available, more high-quality evidence is needed on their efficacy and (cost-)effectiveness, as well as on the identification of suitable candidates for this model of PR.

Summary of evidence and future directions

The key points of this narrative review are summarised in the infographic presented in figure 3. Digital health technologies offer several benefits over traditional models of care and provide opportunities to improve PR access and uptake and promote health-enhancing behaviours in patients with chronic respiratory diseases. Nevertheless, there are still several challenges that need to be considered before its widespread implementation. These include, among others, testing different digital enabled interventions to identify the best modes of implementation considering their purpose (*i.e.* primary PR, physical activity coaching, maintenance), identification of patients' characteristics most likely to succeed with this type of PR, patients' and healthcare professionals' acceptance of technologies, paucity of high-quality evidence, and technical and regulatory issues. The present narrative review addresses these topics and highlights the need to conduct more robust research on the use of digital health in PR, including cost-effectiveness analyses to support its future integration into healthcare settings. Nevertheless, findings should be interpreted with caution as this was a narrative review and, thus, it may be subject to study selection bias.

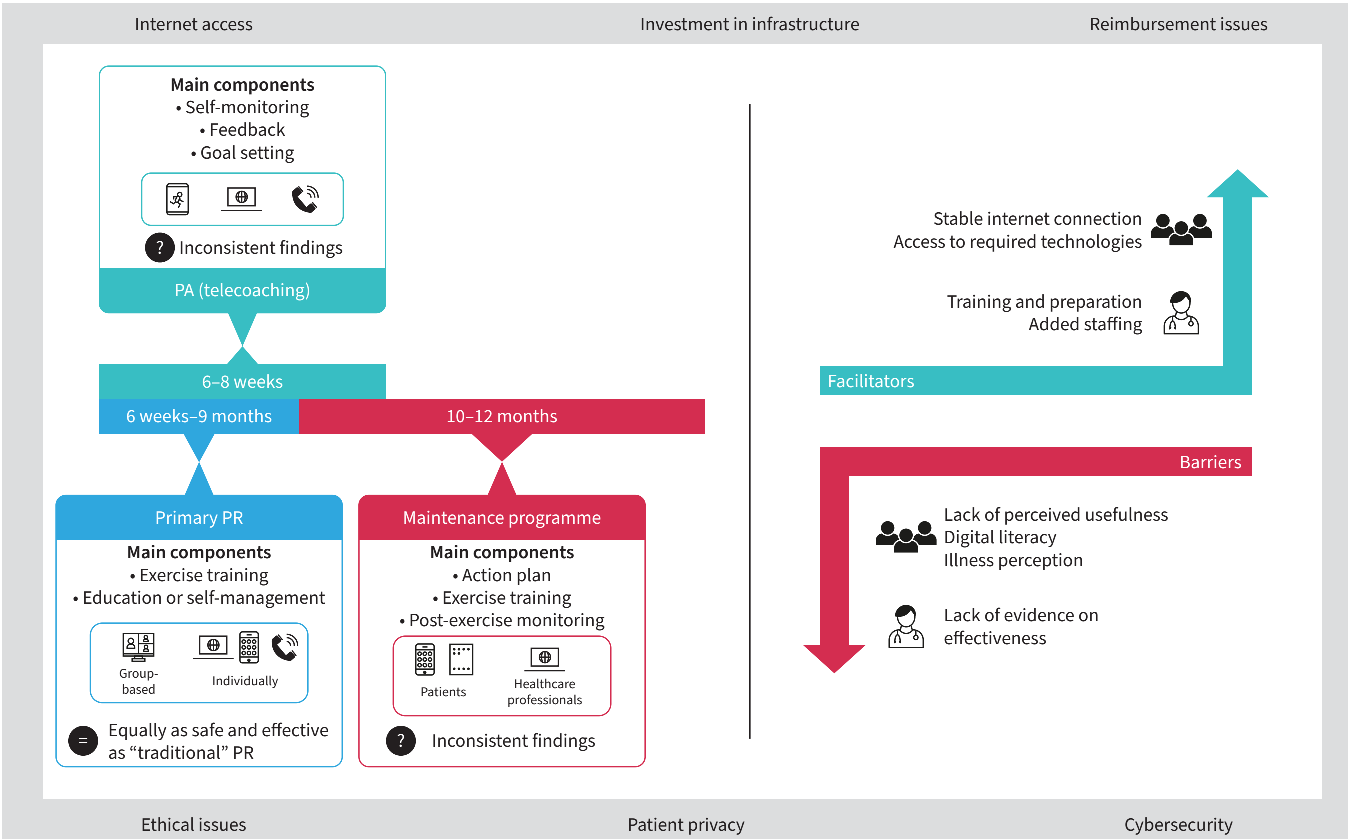

FIGURE 3 Infographic summarising the key points identified in this review on the role of digital health in pulmonary rehabilitation (PR). PA: physical activity. Icons were retrieved from the Microsoft Office Powerpoint (Microsoft Corporation, USA) and the free icon website The Noun Project (https://thenounproject.com/).

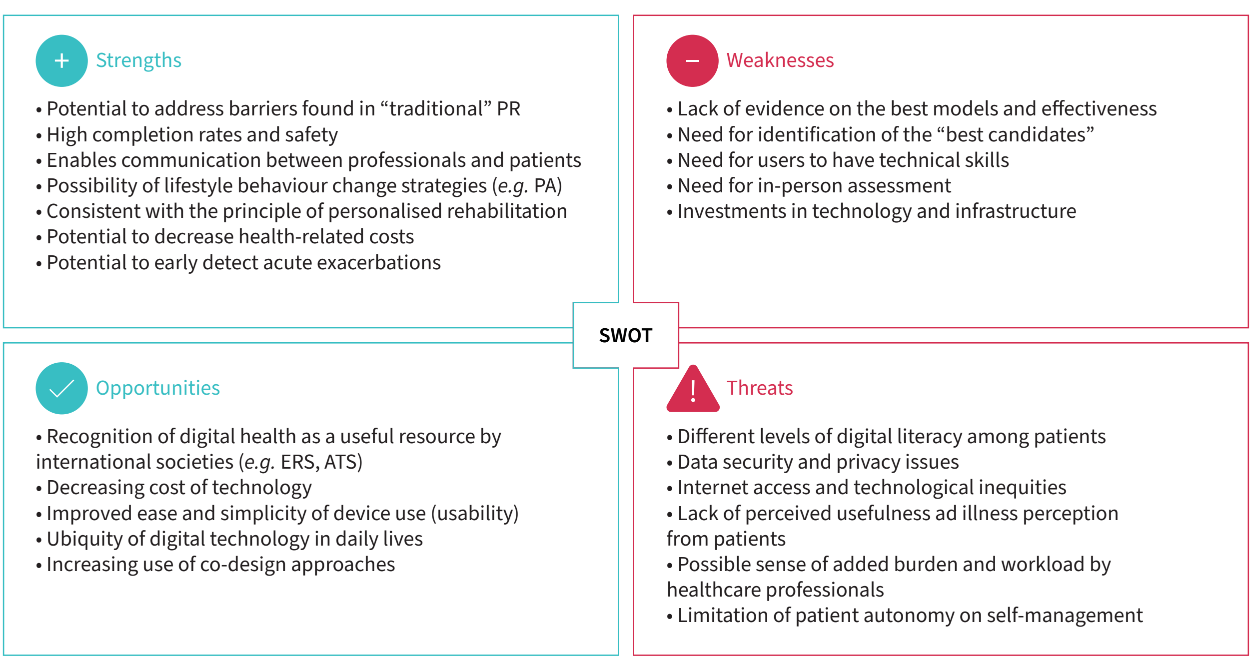

FIGURE 4 A strengths, weaknesses, opportunities and threats (SWOT) analysis of digital health in the context of pulmonary rehabilitation (PR). PA: physical activity; ERS: European Respiratory Society; ATS: American Thoracic Society.

Most of the existing evidence is focused on patients with COPD, as it is the most prevalent chronic respiratory disease worldwide and one of the top 10 causes of mortality and leading causes of disability [109]. Future studies should also focus on other chronic respiratory diseases. Furthermore, some of the studies included in this review lacked information on patient selection and intervention description, which emphasises the need for future research to follow proper guidelines for reporting studies in digital health (*e.g.* mobile health evidence reporting and assessment guidelines if using mobile phones [110]) and/or exercise training [111].

Finally, to summarise the strengths (S) and weaknesses (W), as well as external opportunities (O) and threats (T) of digital health in PR, a SWOT analysis is presented in figure 4, based on data obtained from studies presented in the different topics of this review. Importantly, it should be noted that not all models of PR are expected to be equally suitable for all patients with chronic respiratory disease [25] and that digital health is not intended to replace the more traditional centre-based PR programmes. Instead, it aims to extend the known benefits of PR to a greater number of patients who can benefit from it.

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