Mobile Applications and Wearables for Chronic Respiratory Disease Monitoring

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Abstract

Mobile health (mHealth) has tremendous potential to benefit patients, providers, and the entire healthcare system. Benefits for patients to adopt mHealth include more effective access to health providers, reduced costs of care, and better health control. For physicians and the healthcare system, reasons to embrace mHealth are enhanced health outcomes, facilitated access to patients for care, and decreased time required for administrative tasks. Currently, some mobile apps and wearables dedicated to respiratory health provide medical education and messaging services, enable diary logs, aid with disease self-management, and include educational games. Major challenges for mHealth to be widely adopted include lack of studies demonstrating effectiveness, limited access to technology by all patients, decreased adoption over time, high costs, and data privacy concerns.

Keywords

digital health, cyberhealth, precision medicine, telemedicine, internet, self-management, monitoring, health education, adherence, open science

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Summary

- mHealth increases access to health knowledge and allows monitoring anytime and anywhere (precision medicine).
- Few mobile apps and wearables are dedicated to respiratory health: medical information, messaging services, diaries, lung function self-assessment, educational games, and others.
- Challenges include access to technology, adoption over time, user experience, and data privacy.

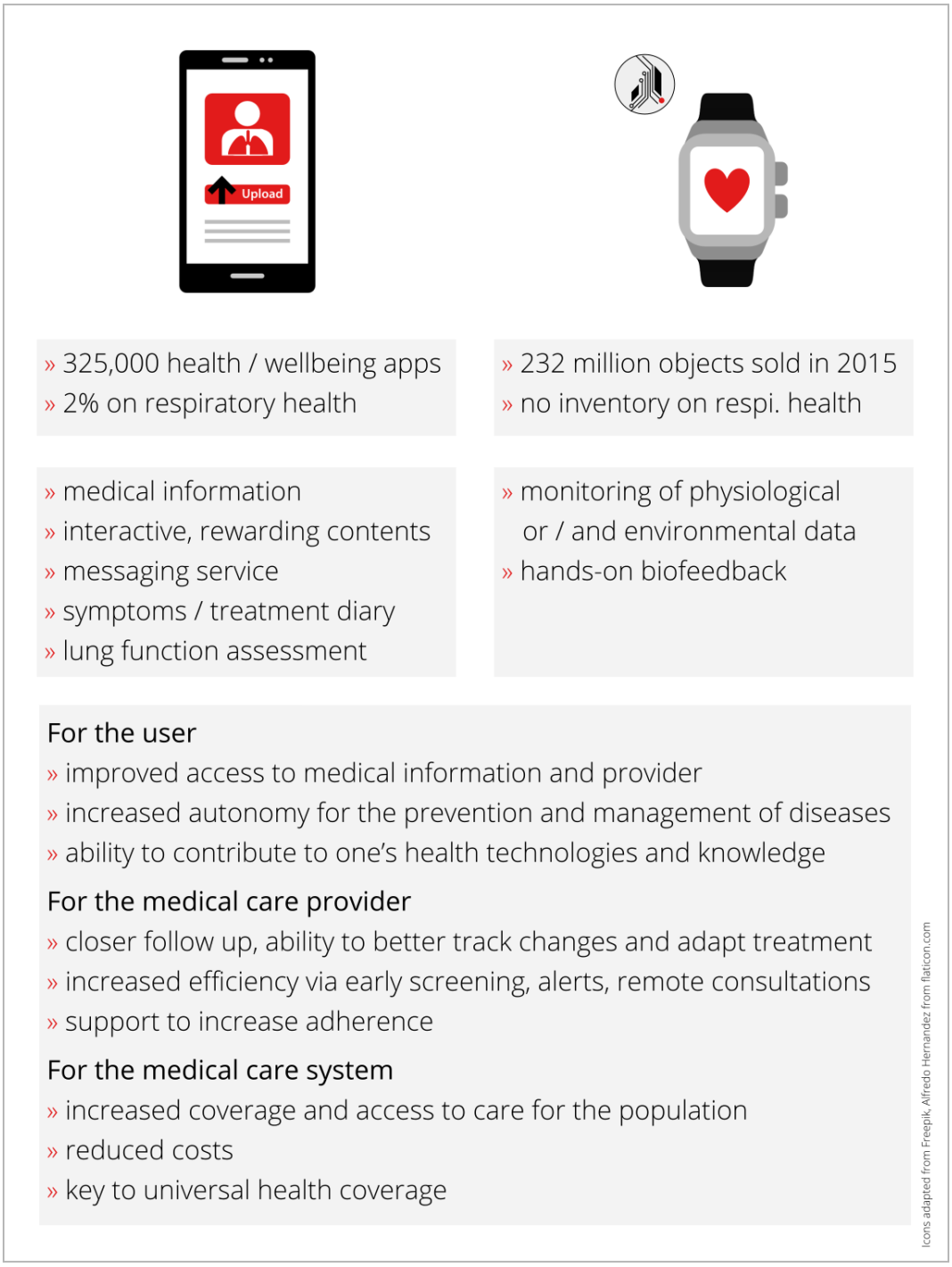

Fig. 1 Mobile apps and wearables in short

Introduction

The omnipresence of connected mobile devices can transform the relationship between patient and medical care provider. *mHealth* is health delivery via mobile devices (1), a subcomponent of *eHealth*—the intention and ways to enhance healthcare with technology (2). mHealth not only provides access to health knowledge anytime and anywhere, it can also collect unprecedented data about patients' daily lives. At every step in the treatment process, mHealth increases patients' autonomy in self-assessing their health and acting to preserve their wellbeing. These technologies can also extend the ability of medical care providers to track their patients' progress and adapt treatments quickly and easily, reducing the need for in-office visits thus reducing the burden on the medical care system.

Mobile applications

Today, over 325,000 mobile applications provide health and wellbeing services (3). The majority of these apps is limited to sending information. Fitness, lifestyle, coping with stress, or nutrition are the focus for 65%, while 23% focus on treatment. Social media is a feature in 65% of the apps. Only 2% connect to a medical care system. Most apps are free to download, one in three requires buying a device, and one in ten is purchased (4).

Most of these apps, 55%, are downloaded less than 5,000 times. However, 3% are downloaded over a million times, reaching a total of 3.7 billion downloads yearly. Only 2% of the apps recommended by medical care providers focus on respiratory health. Respiratory apps have the lowest fill-and-sustain rate among all (4), and less than 1% of people living with asthma use an app on asthma (3).

Apps recommended by clinicians see a retention increase of 10-30%, and 1 in 3 physicians have recommended mHealth apps to their patients (4). However, the larger system continues to fall short—only 2% of hospitals promote the use of apps (5), and apps developed by medical care providers often fail to satisfy the functionalities patients seek: access to medical records, appointment management, and prescription renewals (5).

mHealth benefits patients, providers, and the entire health care system. Three key reasons for patients to adopt mHealth are: more effective provider access, reduced costs of care, and better health control. For physicians, key reasons are: enhanced health outcomes, facilitated access to care for the patients, and decrease of the time required for administrative tasks (6). For the World Health Organization, mHealth is a central element to achieve universal health coverage (7).

Wearables

Wearables are devices worn on the body that track certain bodily functions. They have also become part of daily life with 232 million objects sold in 2015. Mostly worn on a wrist (55%) or on the chest (23%) (4), wearables are primarily used for improving overall wellbeing: exercising, losing weight, sleeping better, and coping with stress among others (7). In the USA, the largest users of wearables are 18-34 year-olds (8).

The following subchapters present current scientific knowledge on mHealth from both patient and provider perspectives.

mHealth from the patient's perspective

The majority of mHealth apps dedicated to treatment are designed to: optimize self-management of chronic diseases and provide greater patient autonomy (10); reduce healthcare resource use (11); and improve clinical outcomes (10-12). Improved self-management occurs through increasing the patient's awareness of symptoms, self-measuring objective parameters such as pulmonary function, maintaining a symptoms diary, and self-managing symptoms. Wearables can further monitor functions and provide physiological and environmental data (13). Smartwatches and sensors worn daily could allow for better embedding of biofeedback and short diaries in the patient's daily routine.

mHealth apps aim to help with self-management, and self-management requires the active participation and engagement of the patient. It is therefore not surprising that the majority of studies evaluating mHealth apps do so from the patients' perspective. In this section, the different aspects of patients' experience with mHealth will be reviewed. This includes apps' usability, perceived benefits, and concerns, with a focus on research pertaining to chronic lung disease apps when available. This figure shows the different aspects of mHealth.

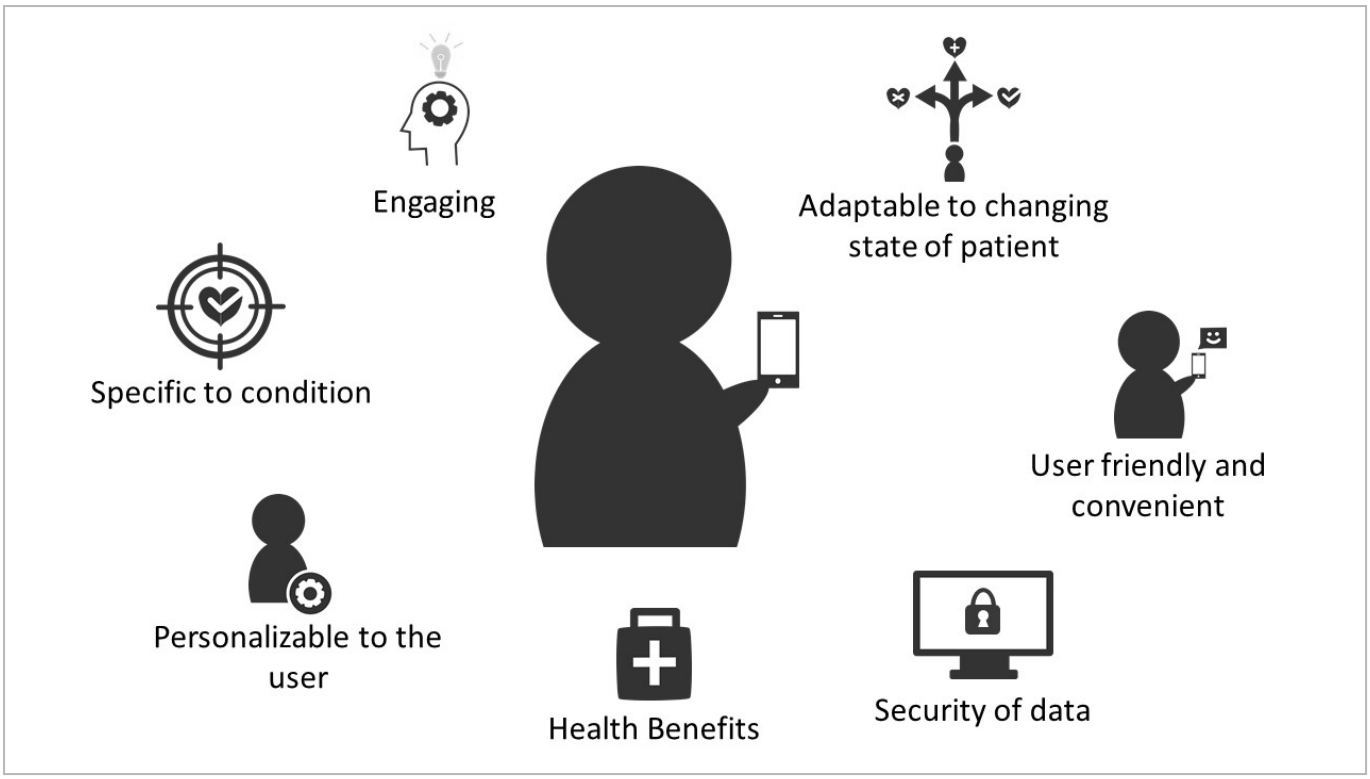

Fig. 2 Elements for successful mHealth

Usability

Usability refers to how well an app functions and serves its intended purposes in a target population (14). It includes user satisfaction and app operability, flexibility, ease of learning, and visual interface attractiveness (15). Usability can be assessed through expert inspection of the app, user observation, surveys, and experimental evaluation to gather user feedback (16, 17). Although international standards and frameworks for software quality evaluation exist, namely those from the International Organization

for Standardization (ISO) (ISO/IEC 25010 (18) and ISO 9241 (19)), few apps are empirically evaluated for their usability (20).

Successful apps are first and foremost characterized by their ability to engage the user, a key element underlying user satisfaction—without user engagement, user boredom and loss of interest quickly ensue. Apps that can sustain positive behavior are more likely to have sustained use (21). Attrition rates in respiratory disease app use can be as high as 28% (22). User engagement can be optimized through integrating game design elements (gamification). Gamification elements include using points or leveling systems, creating leaderboards, using rewards such as badges or trophies, implementing challenges, and integrating social features so users can interact with each other (23, 24). A review of 38 asthma apps (up to April 2016) demonstrated considerable differences between apps, and most apps used little gamification (25): While 74% of the tested apps allowed users to see and "compete" against their own records, a rewards system was only implemented in 8% of them. When the apps' quality was evaluated by the standardized Mobile Application Rating Scale, a measure of health app quality using five subscales (engagement, functionality, aesthetics, information, and subjective quality) (26), asthma apps performed worst in user engagement. Researchers suggested that rewards systems, which have recognized effectiveness in psychology theories and can be implemented easily, should be integrated in future apps.

User engagement matters because the integration of mHealth into a patient's self-management requires long-term use of a technology. Long-term mHealth use is particularly important in chronic lung disease care which requires long-term management (27). The mHealth app needs to be flexible and adaptable to the user's changing needs. Thus, the design of apps for chronic diseases should consider how the patient interacts with their condition over time (e.g. frequency and length of treatments, changes in the condition) (24). Some research showed that most participants using health apps reduced or stopped using their app when they were familiar with the self-management techniques or did not learn any further from the app (21). Moreover, while long-term engagement is essential in determining an app's value in chronic disease management, few studies have evaluated user engagement over time and among those that did, the testing period is usually not long term: under 6 months (22, 28-30).

Wearables may offer increased mHealth opportunities. Smartwatches have limited sensing and computing capability, but their location on the body and extensive patient contact could help transform health function monitoring into an automatism, increasing retention in the long run. Ways to improve the interactivity and user experience of such devices must be researched (31). Wearables such as clothing seem currently only adapted to specific contexts in lung health such as chronic obstructive pulmonary disease monitoring (32-34). Lighter and less constraining, tattoo-like sensor films seem a promising lead that could extend the power of mHealth apps with new sensing possibilities (35). Such easy-to-carry devices could indeed ease patient adoption and use (36). Medication trackers such as inhaler-based monitoring devices could also help patients log their treatment intakes. Combined with physiological data, such a tracker could help adapt the treatment to each patient (37, 38). Clinical research remains very limited regarding wearables in general.

Most apps that have been clinically tested report few technological or operability issues (39). Adults using health apps report an appreciation for automation of in-app functions such as automatic data entry via a sensor or a wearable device (21).

Perceived benefits

A few studies in mHealth documented users' perceived benefits, an important consideration for the app user. Specifically, users report greater self-awareness of their condition, improved self-confidence in chronic disease monitoring, easier integration of self-management techniques, and feeling in control (40). Patients reported decreased anxiety knowing that their health symptoms were monitored (40). A pilot study of an app encouraging home-based pre-lung transplant rehabilitation to treat frailty found summarily positive feedback from users (41). Participants felt in control of their physical status and felt that they could take some action to improve their health rather than just waiting for their next appointment.

Additionally, some apps provided alert systems reminding users to take medications (42, 43) or informing users when health indicators reach the critical range and prompting them to call their health professional (43). Specifically, in designing an app to promote medication adherence in adolescent solid organ recipients, field-test users requested the function of alerts and felt that the app was helpful in tracking their medication intake (42). Other apps transmitted patients' data to their health professionals, a feature that was valued by users because it avoided repeated healthcare visits (21).

Overall, users perceived benefits from using mHealth apps or wearables, though studies are limited in number. However, clinical studies are needed to determine actual health benefits to the user.

mHealth from parents' point of view

Parents also see the benefits of mHealth in managing their children's chronic lung disease. A survey-based study demonstrated that the majority of parents believed the use of an app would help them better monitor and manage their child's asthma. Specifically, parents ranked an app's ability to generate reports for the doctor, input symptoms into a diary, and complete a self-check quiz as the most useful features (44). Parents also appreciate reminder messages to their teenagers to take their medication or to get refills, benefits reiterated by the teenagers as well (45), and felt less need to continuously remind their teenagers to take their medications (42), potentially decreasing parent-adolescent conflict. Thus, parents may also benefit from their children's use of mHealth. Given the increasing societal concern of screen time in children (46), the adoption of mHealth by parents is an important aspect in apps aimed at children. While user involvement in the design of a health app is often viewed as necessary, future studies should also consider parental input in creating mHealth apps aimed at children.

Patients' concerns with mHealth

While patients usually have a positive view of mHealth apps, some concerns remain that may affect the apps' acceptability. Data security is a concern with mHealth, particularly with regard to transmission of sensitive information that may be accessed by health insurers (21). Additionally, using a short message service (SMS) system for asthma self-management, some patients raised concerns about the lack of feedback and unnecessary medicalization (40). Further, while some apps offered distance support (30), most apps do not offer specific training on their use, which led to user engagement issues in some studies where technical barriers inhibited the use of the apps (47, 48). In addition to technical difficulties, literacy barriers, language, and connectivity issues are also potential barriers to mHealth.

In short

mHealth is a patient-centered means to promote self-management of chronic conditions, and its efficacy is highly user-dependent. Thus, understanding mHealth from the patient's perspective is essential. In fact, studies suggest an iterative design process with multiple user experience testing sessions in the development of mHealth apps to optimize user engagement of the final product (39, 49). Several studies documented a generally high usability, acceptability, and user satisfaction of mHealth tools, with most users perceiving benefits from the use of mHealth. However, few studies have assessed long-term user engagement and health benefits. Furthermore, the theoretical framework behind positive behavioral change resulting from using mHealth is poorly understood. Integrating the user early in the design process will maximize user engagement and address their concerns, which could in turn lead to the development of better apps that better meet patients' needs.

mHealth apps from the medical care provider's perspective

Mobile health applications

Few studies have focused on chronic lung disease monitoring, but general studies have reported benefits and barriers to mHealth apps from the viewpoint of providers. In general, more benefits than barriers are reported. A systematic review of 33 studies examining factors influencing healthcare professional adoption of mHealth applications found that their adoption was more often seen as a benefit than a barrier (50). The review found that mHealth app adoption facilitators perceived the mobile device would be more useful over current practice (50). Ease of technology use in the working environment was also very important (50).

Benefits to providers include saving time, better patient engagement, and enhanced care. Physicians can access patient-reported symptoms in the electronic health record (EHR) and review them before in-person visits, saving time discussing symptoms with patients (51). A study of a mobile portal application for hospitalized patients found providers felt the portal improved patient engagement in care and identification of errors (52), and research on a sensor-based mobile intervention for asthma identified mHealth technology as enhancing the patient-centered medical home (53).

Further, in a qualitative study asking providers about their views of a sensor-based mobile intervention for asthma patients, providers were enthusiastic for the mobile health technology if it could provide adherence to prescribed inhaler therapy and data on inhaler technique (53). Providers hoped for data at the scheduled clinic visit and also inter-visit alerts for excessive use of rescue therapy and pulmonologists were interested in the inter-visit lung function data (53).

Other wearable technology research examined provider perceptions of feasibility and acceptability of a self-monitoring intervention to reduce sedentary behavior for individuals with COPD admitted to the hospital for an acute exacerbation. Providers mostly felt this type of technology would be a good idea.

mySinusitusCoach is a mobile app that helps patients with chronic rhinosinusitis log their symptoms and treatments, get recommendations, and learn about the disease. The longitudinal data collected can improve physician follow-up, such as early identification of the need for surgery. Initiated by the European Forum for Research and Education in Allergy and Airway diseases, the app was conceived by

medical care professionals with input from patients, primary care physicians, and pharmacists. The app is currently available in three countries, and research on its health outcomes is ongoing.

Fig. 3 Screenshots of a questionnaire to assess one's symptoms (left) and of themes available (right) in mySinusitusCoach. Source: https://play.google.com/store/apps/details?id=nl.euforea.sinusitishealth&hl=en

eHealth monitoring can supplement traditional care usefully. Researchers in the United Kingdom conducted semi-structured interviews with providers on their views of a telehealth care program for patients with chronic conditions, including chronic heart disease, chronic obstructive pulmonary disease (COPD), and diabetes (55). This telehealth monitoring system included the installation of telehealth equipment, such as pulse oximeter and weighing scales, in the patient's home; patients recorded their biometric readings which were transmitted to healthcare professionals and reviewed and monitored remotely by nurses or community matrons. When parametrics were outside of the normal range, nurses and community matrons contacted the patients and/or referred them to other healthcare professionals such as the physician. The majority of providers felt that this telehealth monitoring system can empower the patient and was a good supplement for traditional patient care (55).

eHealth offers many favorable facets to providers, yet obstacles remain, primarily regarding the disruption of workflow (56): Organizations were not designed or created to accommodate mHealth, so adapting to new workflow demands can bring challenges (56). The primary concern is the increase in workload with implementation of (55) mHealth (57) apps (58). Undefined and changed roles occur when the mHealth app leads to different providers being responsible for a workflow task or no responsibilities are assigned (59), and providers now have to invest a significant amount of time with patients if they

need to teach patients how to use the technique and analyze the data reported through the mHealth app (60). Additionally, workflow is disrupted as providers are unable to complete the work process in a linear and smooth manner (58). Moreover, lack of alignment with existing clinical processes poses a barrier when the mHealth app does not integrate with or support the current workflow systems in place (55). Another concern for department-specific mHealth protocols is that every time providers change departments, whether rotating between departments or are short-term hires, they will need to learn a new mHealth app (56).

Some research unearthed a couple of provider concerns beyond those involving workflow. First, face-to-face communication may be undermined as direct personal contact between patient and provider may decrease (61). Moreover, data accuracy is a concern with protection of health information, sensor-based mobile intervention for families who share inhalers, and access to smartphones (53).

Providers also had concerns about the effect of the mobile technology on the patients. In a study of a mobile portal application for hospitalized patients, providers worried that additional features might result in a volume and complexity of information that could be overwhelming for patients (52). In addition, providers raised concerns regarding a potentially high volume of tests performed, the high percentage of abnormal test results, and patients' limited ability to interpret results in the context of their acute illness (52). Also, some older patients may have difficulty using technology.

Wearables

Few studies to date have evaluated wearables for chronic lung disease management. Most eHealth studies on wearables have focused on development and feasibility of monitoring activity, and no studies have found evidence supporting sustained use of wearables or effects on health outcomes (62). Development and feasibility studies have been conducted for pulmonary rehabilitation (62), detecting wheeze (63), and monitoring pulmonary edema in adult respiratory distress syndrome (64). One study sought to improve the care of individuals with COPD and reduce hospitalizations by using smartwatches to detect early exacerbations in time for intervention (65). The smartwatch collected sensor data including heart rate, accelerometer, and gyroscope recordings, and researchers concluded that individuals wanted to actively engage with the smartwatch and receive feedback about their activity, heart rate, and how to better manage their COPD, but further work is necessary to improve the patient experience (65).

mHealth apps from the healthcare system view

Three of the main issues to address from the health care system perspective are cost-effectiveness, privacy, and diffusion of health innovation. Cost-effectiveness analyses help policy makers decide how to allocate limited resources, and insurers often use cost-effectiveness analyses to decide whether to cover health interventions (66, 67). Risks to privacy with mHealth are an important consideration by the healthcare system as mHealth technologies collect detailed personal data (68). Communication of these risks for the purposes of informed consent are critical (68). As mHealth is essential to achieve universal health coverage (7), its diffusion is critical. Geographic and financial accessibility are two current challenges (69).

Cost-effectiveness

Cost-effectiveness is a method of economic evaluation that can be helpful in health technology assessment and is often expressed in terms of the ratio of the cost associated with health gain divided by gain in health from a measure (70). The gain in health from a measure is often measured in terms of the quality adjusted life year (QALY) so that multiple interventions can be compared (66, 67). Cost-effectiveness analysis produces the incremental cost-effectiveness ratio in units of dollars per QALY (66, 67). Cost is an important component that will contribute to the success or failure of mHealth apps. On a broad level, many expect that mHealth apps will bring cost reductions. Currently most studies report on the implementation process of mHealth apps rather than measuring costs and financial benefits after implementation. Thus, most studies do not address the actual costs (60). Many health care system representatives believe that costs are the most important component contributing to the success or failure of mHealth apps. Authors of a review paper concluded that institutional adoption of mHealth apps can be considered when organizations break even or profit, but is more difficult to consider with a financial loss (60). Thus, national policy investments and health insurer reimbursement to providers for app adoption and usage may play a critical role in their adoption (60).

While no studies specifically study mHealth and chronic lung diseases, we can learn from the general mHealth literature even though it is also limited. In addition to costs related to development and implementation of mHealth apps, there are the costs of equipment, staffing, and communication (71). One study did assess the cost-effectiveness of outpatient pulmonary subspecialty consultations in rural populations, finding that telemedicine was more cost-effective compared to routine care where patients travel from a remote site to the hub site to receive care, and the main driver of cost-effectiveness was the ability to cost share as providers can share telemedicine infrastructure and patients suffer fewer costs from lost productivity (72).

Respi Heroes is a mobile game that aims to make respiratory health accessible and fun through learning by playing. The player can explore different environments (mountain, city field of pampas, etc.), interact with characters who provide cultural and health knowledge (the air, the lung system, nutrition, food, physical activity, etc.), and play different mini-games according to their health condition (memorizing asthma triggers, matching the inhaler with the correct situation, self-assessing one's lung capacity, reducing one's stress, etc).

The game and game controller that transform the breath into data (game input and self-assessment of lung function) are developed in a participatory action research approach. Research is ongoing in Canada, France, Switzerland and Italy on user experience, health outcomes, and the co-creation process. The game and reproducible controller are expected to be publicly available mid-2019, covering asthma, cystic fibrosis, and respiratory health promotion.

Unlike most mHealth projects, the source code of the game and design of the controller are documented and released under fair use licenses to allow interested communities to enhance and adapt the work done. This open science approach allows us to reduce the cost of access to health by mutualizing resources across countries. The initiative is led by the *Breathing Games* commons, a participant of the *Global Alliance against Respiratory Diseases*.

Fig. 4 Screenshots of a game scene to learn how to cope with an asthma attack (left), of a scene to self-assess one's lung capacity (right), and of a game controller (below). Source: https://www.breathinggames.net, CC BY-SA

Studies of eHealth effectiveness are needed to help inform its cost-effectiveness. One review of mobile apps for asthma found that only two randomized controlled trials met their inclusion criteria which was to compare patient self-management asthma interventions delivered via smartphone apps to those delivered via traditional methods (74). They concluded that there is not enough evidence to advise providers to use asthma self-management programs via smartphone and table computer apps (74). In order for effectiveness studies to be conducted, participation is important. One study attempted to examine e-technology as a clinical monitoring tool following palliative radiotherapy for lung cancer, but only one of 17 providers contacted agreed to participate in the study so the benefits of the technology could not be assessed (75). The lack of providers accepting participation in this study suggests that there are still uncertainties about adoption of mHealth.

Privacy

The health information that can be collected from mHealth technology has great potential value, but there are special privacy risks that need to be addressed. These risks include the potential for discrimination from insurers, such as the nonpurposeful collection of data of family members (76). In medical settings, the Common Rule and the Health Insurance Portability and Accountability Act (HIPAA) requires high standards for the protection of patient and research participant data (77). However, mHealth technologies used in medical care often come from the commercial sector; thus, ensuring these mHealth technologies meet the high standards of privacy protection is important and challenging (78, 79). Commercially developed technologies usually have long informed-consent forms, sometimes stipulating the release or selling of personal identifiable data. Furthermore, commercial data collection, transmission, storage, access and use are underregulated and not standardized (77), and health care systems need to use strategies to protect the privacy of patients.

Diffusion of health innovation

mHealth is essential to achieve universal health coverage by 2030, a United Nations Global Goal [69]. mHealth can widen the number of individuals who can access health services, increase the amount of services available, and reduce the cost of access to such services [80].

In 2016, 109 countries reported having at least one mHealth program. The most common services offered were free calls to emergency and medical services, as well as appointment reminders—an effective means to reduce no-shows in consultations. Only 25 countries reported evaluations on the safety, quality, and reliability of mHealth programs. Access to mHealth was also difficult to assess. Indicators of access should thus be implemented in every mHealth project, with special consideration to priority audiences such as vulnerable and marginalized populations [1].

In addition to addressing disease management, mHealth should encompass health promotion and primary prevention. In the European Union alone, respiratory mHealth apps could help 4 million Europeans quit smoking, and 1 million Europeans reduce the risk of developing COPD [81]. In Europe, mHealth could reduce the cost of medical care by 99 billion euros when all diseases are considered. Such potential remains theoretical until a large audience adopts and uses mHealth over the long term.

To ensure that mHealth provides high quality of care and meets local needs, individuals and communities must be involved in the conception, production, and evaluation of such technologies [69]. Unfortunately, most projects use standard copyright licenses, which forbid individuals and communities to take ownership of the innovation. Alternative licenses such as the GNU Affero General Public License [82] or the CERN Open Hardware License [83] could encourage populations to engage in mHealth projects by ensuring usability is high, as well as improving source code of apps or design of wearables. Projects released under fair use licenses or in the public domain could foster an approach where the individual (before and beyond their disease) is at the core and where medical experts or researchers become partners. Free and open source projects also increase reproducibility of work, allow people from different countries to join their knowledge and experience to reach a common goal (crowdsourcing), and enable design of tools that are appropriate even in low resource settings. Combined with new ways of doing research [84], free mHealth apps and open source mHealth wearables could accelerate the pace of innovation [85], stimulate individuals to contribute to the respiratory health of their communities, democratize respiratory health knowledge, and reduce the burden on the healthcare system.

Conclusion

Widespread adoption of mHealth will occur over time. mHealth can help individuals adopt healthy lifestyles, deepen their knowledge about health, and get support to self-assess and manage dis- eases. mHealth can help medical care providers improve follow-up care of their patients and increase their efficiency by allowing for earlier diagnosis and remote consultations. At the level of healthcare systems, mHealth can help achieve universal health coverage.

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