

Available online at www.sciencedirect.com

Public Health

journal homepage: www.elsevier.com/puhe

Review Paper

How do mobile health applications support behaviour changes? A scoping review of mobile health applications relating to physical activity and eating behaviours



O. Aromatario ^{a,*}, A. Van Hoya ^b, A. Vuillemin ^c, A.-M. Foucaut ^d,
C. Crozet ^d, J. Pommier ^a, L. Cambon ^e

^a UMR 6051, ARENES, EHESP, Paris, France

^b EA 4360, APEMAC, Université de Lorraine, Nancy, France

^c Université Côte d'Azur, LAMHESS, Nice, France

^d Health Education and Practices Laboratory-LEPS (EA 3412), University of Paris13-Sorbonne Paris Cité, Bobigny, France

^e Chaire Prévention, ISPED, Centre de Recherche Inserm-Université de Bordeaux U1219, BPH, Université de Bordeaux, Bordeaux, France

ARTICLE INFO

Article history:

Received 26 February 2019

Received in revised form

3 June 2019

Accepted 19 June 2019

Available online 30 July 2019

Keywords:

e-health

Behaviour

Effectiveness

Eating habits

Physical activity

Prevention

ABSTRACT

Objective: The objective of this review was to analyse how researchers conducting studies about mobile health applications (MHApps) effectiveness assess the conditions of this effectiveness.

Study design: A scoping review according to PRISMA-ScR checklist.

Methods: We conducted a scoping review of efficacy/effectiveness conditions in high internal validity studies assessing the efficacy of MHApps in changing physical activity behaviours and eating habits. We used the PubMed, Web of Science, SPORTDiscus and PsycINFO databases and processed the review according to the O'Malley and PRISMA-ScR recommendations. We selected studies with high internal validity methodologies (randomised controlled trials, quasi-experimental studies, systematic reviews and meta-analyses), dealing with dietary and/or physical activity behaviours; covering primary, secondary or tertiary prevention and dealing with behaviour change (uptake, maintenance). We excluded articles on MHApps relating to high-level sport and telemedicine. The process for selecting studies followed a set protocol with two authors who independently appraised the studies.

Results: Twenty-two articles were finally selected and analysed. We noted that the mechanisms and techniques to support behaviour changes were poorly reported and studied. There was no explanation of how these MHApps work and how they could be transferred or not. Indeed, the main efficacy conditions reported by authors refer to practical aspects of

Abbreviations: Apps, Applications; BCT, Behaviour Change technique; MHApps, Mobile Health Applications.

* Corresponding author. 20 avenue George Sand, 93210 La Plaine Saint Denis, France. Tel.: +33 0603139897.

E-mail addresses: olivier.aromatario@ehesp.fr (O. Aromatario), aurelie.van-hoya@univ-lorraine.fr (A. Van Hoya), Anne.VUILLEMIN@unice.fr (A. Vuillemin), audemarie.foucaut@univ-paris13.fr (A.-M. Foucaut), crozet@univ-paris13.fr (C. Crozet), jeanine.pommier@ehesp.fr (J. Pommier), linda.cambon@u-bordeaux.fr (L. Cambon).

<https://doi.org/10.1016/j.puhe.2019.06.011>

0033-3506/© 2019 The Authors. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

the tools. Moreover, the issue of social inequalities was essentially reduced to access to the technology (the shrinking access divide), and literacy was poorly studied, even though it is an important consideration in digital prevention. All in all, even when they dealt with behaviours, the evaluations were tool-focused rather than intervention-focused and did not allow a comprehensive assessment of MHApps.

Conclusion: To understand the added value of MHApps in supporting behaviour changes, it seems important to draw on the paradigms relating to health technology assessment considering the characteristics of the technologies and on the evaluation of complex interventions considering the characteristics of prevention. This combined approach may help to clarify how these patient-focused MHApps work and is a condition for improved assessment of MHApps in terms of effectiveness, transferability and scalability.

© 2019 The Authors. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Mobile health applications (MHApps) are becoming a major feature of our daily lives. For instance, according to Statista,¹ in 2019, the number of mobile phone users worldwide is forecast to reach 4.68 billion. According to *Le livre vert de la santé mobile*, half of them use MHApps.² The MHApps referred to by Aungst³ as ‘patient-focused’ are increasingly used for smoking cessation, changing eating habits and physical exercise.^{2,4} These patient-focused MHApps are used for health promotion, communication, health monitoring and reminders for taking medication. They may be associated with connected devices used for automatic data collection.

Although MHApps are now considered as a new mode of prevention,⁵ 39% of commercial health apps are thought to be used no more than 10 times before being abandoned.⁶ There is no community consensus on their effectiveness, which depends on many factors not reported in studies.⁷ Indeed, numerous works have addressed the factors of effective health behaviour changes in MHApps,⁸ but Petit and Cambon have shown that these factors are barely reported in evaluation studies.⁹ For instance, a comparative descriptive assessment of the top-rated free apps in the health and fitness category available in the Apple Store® shows that few apps in this category are theory-based.¹⁰ The same observation can be made about studies on MHApps related to physical activity behaviours.¹¹ In the same vein, the most popular commercial apps for managing weight have been shown to provide suboptimal quality for fulfilling their purpose.¹² Yet evaluation studies, notably experimental studies offering internal validity, are what inform practitioners and decision-makers in using apps in practice. So the question is: if experimental design is the best way to assess the efficacy/effectiveness of apps in terms of behaviour changes, how should the different factors influencing results be considered to inform practitioners and decision-makers more accurately? In other words, how can effectiveness mechanisms be explored? To answer this question, we conducted a scoping review.¹³ The objective of this review is to analyse how researchers conducting studies about MHApps effectiveness assess the conditions of this effectiveness. We decided to focus on the two positive health

determinants most commonly addressed by MHApps: eating habits and physical activity.² This article presents and discusses the method and the results of this review, highlighting the methodological challenges of assessing prevention MHApps.

Methods

Design

We conducted a scoping review¹⁴ because such reviews ‘are exploratory and systematically sift through available literature on a particular subject, identifying key concepts, theories, sources of conclusive evidence and knowledge gaps [...]’.¹⁵ It thus suited our purpose. We followed the five stages described by Arksey and O'Malley:¹⁴ (1) identifying the research question; (2) identifying relevant studies; (3) selecting studies; (4) charting the data; and (5) collating, summarising and reporting the results. We also applied the preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews (PRISMA-ScR guideline¹⁶) (in our study, all of the items are relevant except 10, 11, 12: these data items are outside the scope of our objectives).

Full electronic search strategy

We performed a literature search using the following keywords: BEHAVIOR AND ‘NUTRITION OR DIET’ AND ‘SMART OR EHEALTH OR MHEALTH’ AND ‘HEALTH PATHWAY OR COACHING OR E-COACHING’ AND CARE. The keywords were chosen during a meeting with all the authors. We searched in the PubMed, Web of Science, SPORTDiscus and PsycINFO databases. These databases were chosen because they are multidisciplinary, including human sciences. They fit our research objective of selecting experimental studies.

We searched for all original (referring to original research) and methodological articles indexed between January 2005 and January 2017 in English or in French and selected relevant articles according to the following criteria: assessing the effectiveness of patient-focused smart devices and applications; evaluation with high-internal validity methodologies (randomised controlled trial, quasi-experimental study,

systematic review, meta-analysis); dealing with dietary and/or physical activity behaviours; covering primary, secondary or tertiary prevention; and dealing with behaviour change (uptake, maintenance). We excluded articles on MHApps relating to high-level sport and those dealing with MHApps in telemedicine (tele-expertise). We selected the identified articles on the basis of their abstracts through double reading using the Covidence software.¹⁷ The complete articles were analysed using the NVivo 11 software®.

Data analysis

Our aim was to understand how researchers assess effectiveness conditions in their studies. First, we conducted a description of articles covering eight dimensions defining the scope of assessment of apps: characteristics of the population, state of health of this population, health determinant targeted, design, tools used, activities included in MHApps, level of action and outcomes in terms of behaviour change. Table 1 shows the eight scoping dimensions with subcategories and objects for analysis.

Second, we analysed how the mechanisms of effectiveness were reported. We considered the mechanisms as per Michie's definition.¹⁸ In the articles, we looked more specifically for:

- The behaviour change techniques (BCTs) used, according to the taxonomy by Michie et al.¹⁸ and Cane et al.,¹⁹ defined as 'active ingredients within the intervention designed to change behaviour'.
- The classical psychosocial theories used without prior classification (e.g. social cognitive theory from Bandura,²⁰ transtheoretical model from Prochaska,²¹ etc.).
- All other mechanisms reported by authors.

Results

We identified 2585 articles. We removed 604 duplicates, bringing the number of abstracts selected to 1981. After reading the abstracts, we selected 89 complete articles to read. We excluded articles dealing with behaviour coaching without the use of MHApps, ones that did not assess patient-focused applications and ones that did not provide any details, even minimal (participation, adherence), about the behaviour change process assessed. After reading, we finally selected 22 articles for analysis. The flow chart (Fig. 1) shows our selection method. The 22 articles selected were original studies.

Description

The 22 articles were analysed and classified according to the eight dimensions described below. Table 2 presents how the articles were distributed across these dimensions. To summarise, the major part (20 articles) of articles dealt with adult people. 13 articles covered ages over 60 years. Social inequalities and social gradient are only occasionally mentioned in the articles and often reduced to the issue of access to the technology. The other sources of inequalities such as literacy level or cultural access are poorly reported and without an explanation of the mechanisms involved.

Table 1 – Description of articles.

Dimensions	Subcategories and objects for analysis
Characteristics of the population using MHApps	Age: • 0–17 years (children- adolescents) • 18–59 years (adults) • + 60 years (older adults) For those articles in which two categories overlapped, even partially, (e.g. 18–70 years), both categories were analysed together Sex: • Male • Female • Males + females Hardship/financial insecurity This category was included if articles explicitly mentioned low-income populations or those with little access to healthcare services
State of health	• Without illness • Chronic illness • Acute illness
Health determinant targeted	• Physical activity (PA) • Diet (D), PA and D • PA and D and other(s)
Designs	• Randomised control trial • Quasi-experimental study • Meta-analysis • Systematic review
Tools used	• Connected device with an application • Smartphone application without a connected device
Activities	• Coaching by text messaging (SMS, messenger, e-mail), face to face or working group, phone • Web-based exchange, forum • Focus group • Self-help support
Level of action	• Individual • Collective • Social • Environmental • Set-up of healthcare services and policy
Outcomes in terms of behaviour change	• Behaviour change • Maintenance of the new behaviour
MHApps, mobile health applications.	

In total, 16 articles dealt with primary prevention (no illness), eight articles dealt with tertiary prevention for treating chronic illness and two dealt with both primary and tertiary prevention. In all the articles, programs essentially acted upon behavioural and individual determinants. However, six articles out of 22 mentioned some of social determinants: involvement of friends and families, members of users' communities and the use of social media. Just one article mentioned the environmental determinant without further exploration. Most MHApps combined diet and physical activity and are associated with a third theme: stress. Most articles

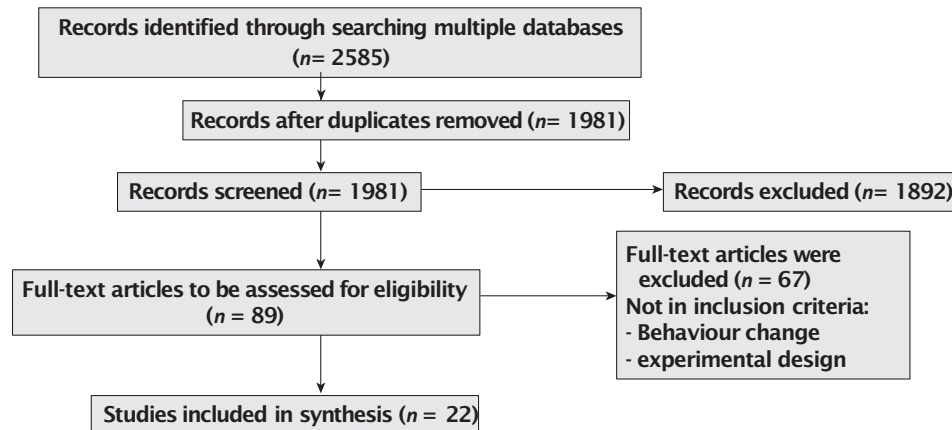


Fig. 1 – Flow chart of article selection process.

dealt with smartphone apps without smart devices, five with connected objects combined with an app. Finally, all articles explored the start of behaviour change. Among them, only five of them dealt with the maintenance of behaviour change, one of them exclusively.

Analysis of effectiveness conditions

Table 3 shows the classification of articles according to focal points addressing the effectiveness conditions described in the Methods section: psychosocial theories and taxonomy of BCTs.

Use of theories or taxonomy to understand mechanisms of efficacy

Twelve articles mentioned the use of a theory.^{22–33} In all, six theories were identified: five articles cited Classical learning theories,³⁴ three articles cited the Transtheoretical model,³⁵ one article cited Relapse prevention,³⁶ nine articles cited Social cognitive theory,²⁰ two articles cited Theory of planned behaviour³⁷ and one article cited Ecological perspective.³⁸ However, although these theories were mentioned, the articles did not explain how they are used to build the MHApps. It is interesting to note that the cost of apps does not influence the use of theories.³⁹ In the same vein, only 15 articles used specific change techniques.^{22–26,29–33,40–44} Michie's taxonomy is cited in two articles.^{18,19} The four most used BCT categories in these 15 articles are as follows: goals and planning (11 articles), feedback and monitoring (nine articles), shaping knowledge (eight articles) and social support (seven articles). This is consistent with the main uses of MHApps, the quantified self and data sharing.⁹

Though few studies attempted to objectify the mechanisms of efficacy through theories or BCTs, some authors^{26,31} pointed out that different mechanisms can be used to improve motivation, especially among young adults: health status, social image or individual factors such as emotions, self-esteem or self-confidence.

Other efficacy conditions

Some authors reported other conditions that may influence results, especially practical conditions: practical use

(ergonomics) and communication modes, especially the ability to cater to user needs (as a first-line aid and, over time, the ability to adapt to the needs of users in their environment) and access to the health system (geographic and social). Indeed, the ergonomic factor relates to convenience, with users seeming to prefer uncluttered screens and menus that are easy to browse: rapid, responsive and relevant to user needs and with relevant and timely messages and notifications.^{29,31} Adaptability offers users the opportunity to modify the environment.⁴⁵

The type of message is important: users prefer and are more sensitive to messages relating directly to behaviour such as short daily or weekly feedback messages,²⁹ motivational messages, incentives for self-monitoring or progress reports,⁴³ tips and hints.²⁹ Messages containing general health information are less appreciated. Self-monitoring can be a sensitive issue, because it may be perceived as a form of control and thus have a negative impact on the use and effectiveness of the app. The challenge is to personalise the relationship between user and tool as much as possible. This could include gaming elements⁴⁶ which may increase users' motivation to lose weight, for example.⁴³ A combination of tools along with their functions and features would be more appropriate than just a single method; for example, a web portal to support an app,²⁷ or telephone support (maximum 15 min).²⁷ Similarly, complementary personal coaching is required.^{26,27,29,31,47} Finally, effectiveness depends on a high level of motivation,⁴³ and we observed that the main techniques used in apps aim to increase motivation.

Discussion

An insufficient process evaluation for MHApps

Our question was how do researchers explore the efficacy/effectiveness conditions of MHApps in experimental studies? To answer, we proceeded to a scoping review. Findings show that although process evaluation could shed light on the mechanisms of efficacy, as it would help to understand how an intervention works, in these studies this evaluation is insufficient to answer this question. In the studies analysed,

Table 2 – Characteristic of the articles according to the eight dimensions for analysis.

Articles	Characteristics of the user population	State of health	Determinant	Design	Tools		Activities included in the MHApps				Levels of action	Outcomes in terms of behaviour changes
					App	Connected device (Yes:present, No: not present)	Coaching			Web-based exchange forum		
							Text messaging (SMS, messenger, e-mail)	Face to face or working group	Tel			
Alley et al., 2014 ²⁴	18–59 yrs male + female	No illness	Physical activity	Randomised Controlled Trial (RCT)	No	No	Yes	No	No	Yes	Individual	Behaviour change in progress and maintaining the new behaviour
B. Spring et al., 2013 ²⁵	18–59 yrs over 60 yrs male + female	No illness	Physical activity and eating and other(s)	RCT	Yes	No	No	Yes	Yes	No	Individual	Behaviour change in progress
Batch et al., 2014 ²⁶ and Svetkey et al., 2015 ³¹	18–59 yrs male + female	No illness	Physical activity and eating and other(s)	RCT	Yes	No	Yes	Yes	Yes	No	Individual Collective	Behaviour change in progress and maintaining the new behaviour
Cadmus-Bertram et al., 2016 ⁴⁰	18–59 yrs over 60 yrs Female	No illness	Physical activity and eating and other(s)	RCT	Yes	Yes	No	No	Yes	Yes	Individual Collective	Behaviour change in progress
Dennison et al., 2014 ²⁷	18–59 yrs over 60 yrs male + female	No illness	Physical activity and eating	RCT	No	No	No	No	Yes	Yes	Individual	Behaviour change in progress
Hartman et al., 2016 ²²	18–59 yrs over 60 yrs Female	No illness	Physical activity and eating	RCT	Yes	Yes or No	No	No	Yes	Yes	Individual	Behaviour change in progress
Hughes et al., 2011 ⁴²	18–59 yrs over 60 yrs male + female	No illness + Chronic illness	Physical activity and eating and other(s)	RCT	No	No	Yes	Yes	Yes	Yes	Individual	Behaviour change in progress
Laing et al., 2014 ⁴³	18–59 yrs over 60 yrs male + female	No illness	Eating	RCT	Yes	No	No	No	No	Yes	Individual Collective	Behaviour change in progress
Nguyen et al., 2013 ²⁸	0–17 yrs male + female	No illness	Physical activity and eating	RCT	No	No	Yes	Yes	Yes	No	Individual Collective	Maintaining the new behaviour
Partridge et al., 2016 ²⁹	18–59 yrs male + female	No illness	Physical activity and eating	RCT	No	No	Yes	Yes	Yes	Yes	Individual Collective	Behaviour change in progress and maintaining the new behaviour
Peacock et al., 2015 ⁴⁴	18–59 yrs over 60 yrs male + female	No illness + Chronic illness	Physical activity	RCT	Yes	Yes	No	No	No	Yes	Individual	Behaviour change in progress

Pellegrini et al., 2012 ³⁰	18–59 yrs male + female	No illness	Physical activity and eating	RCT	Yes	Yes or No	No	Yes	Yes	Yes	Individual Collective	Behaviour change in progress
Quinn et al., 2011 ³²	18–59 yrs male + female	Chronic illness	Physical activity and eating and other(s)	Cluster Randomised Trial	Yes	Yes	Yes	No	Yes	No	Individual	Behaviour change in progress
Ratanawongsa et al., 2014 ²³	18–59 yrs over 60 yrs male + female In hardship	Chronic illness	Physical activity and eating	Stepped Wedge Control Randomised Trial	No	No	No	No	Yes	No	Individual	Behaviour change in progress
Reid et al., 2012 ³³	18–59 yrs over 60 yrs male + female	Chronic illness	Physical activity	RCT	Yes	Yes	Yes	Yes	No	Yes	Individual	Behaviour change in progress
Sangster et al., 2015 ⁴¹	18–59 yrs over 60 yrs male + female	Chronic illness	Physical activity and eating	RCT Cost utility analysis	Yes	Yes	No	No	Yes	No	Individual	Behaviour change in progress
Spasova et al., 2016 ⁶⁹	18–59 yrs over 60 yrs male + female	No illness	Physical activity and eating and other(s)	RCT	No	No	No	No	Yes	No	Individual	Behaviour change in progress
Taveras et al., 2012 ⁷⁰	0–17 yrs male + female In hardship	No illness	Physical activity and eating and other(s)	RCT	No	No	Yes	Yes	Yes	No	Individual Environment	Behaviour change in progress
van Berkel et al., 2014 ⁴⁵	18–59 yrs male + female	No illness	Physical activity and eating and other(s)	RCT	No	No	No	No	No	Yes	Individual	Behaviour change in progress
van Vugt M. et al., 2013 ⁴⁷	18–59 yrs over 60 yrs male + female	Chronic illness	Physical activity and eating and other(s)	RCT	No	No	Yes	Yes	No	Yes	Individual	Behaviour change in progress
Wayne et al., 2015 ⁶	18–59 yrs over 60 yrs male + female In hardship	Chronic illness	Physical activity and eating and other(s)	RCT	Yes	No	Yes	Yes	Yes	No	Individual	Behaviour change in progress
MHApps, mobile health applications.												

Table 3 – Behaviour change techniques and change theories.

Articles	Behaviour change techniques (among the 16 BCTs' categories)	Behaviour change theories
Alley et al., 2014 ²⁴	(1) Scheduled consequences (8) Feedback and monitoring (10) Social support (15) Shaping knowledge	Classic learning theories ³⁴ Theory of planned behaviour ³⁷
B. Spring et al., 2013 ²⁵	(8) Feedback and monitoring (9) Goals and planning (10) Social support (11) Comparison of behaviour (12) Self-belief	Transtheoretical model ²¹ Relapse prevention ³⁶ Social cognitive theory ²⁰ Theory of planned behaviour ³⁷
Batch et al., 2014 ²⁶	(8) Feedback and monitoring (9) Goals and planning	Social cognitive theory ²⁰
Svetkey et al., 2015 ³¹	(10) Social support (15) Shaping knowledge	Transtheoretical model ²¹
Cadmus-Bertram et al., 2016 ⁴⁰	(9) Goals and planning (15) Shaping knowledge	
Dennison et al., 2014 ²⁷		Social cognitive theory ²⁰
Hartman et al., 2016 ²²	(10) Social support (15) Shaping knowledge	Classic learning theories ³⁴
Hughes, et al., 2011 ⁴²	(5) Associations (8) Feedback and monitoring (9) Goals and planning	
Laing et al., 2014 ⁴³	(2) Reward and threat (10) Social support (11) Comparison of behaviour	
Nguyen et al., 2013 ²⁸		Classic learning theories ³⁴
Partridge et al., 2016 ²⁹	(9) Goals and planning (15) Shaping knowledge	Classic learning theories ³⁴
Peacock et al., 2015 ⁴⁴	(8) Feedback and monitoring (9) Goals and planning	
Pellegrini et al., 2012 ³⁰	(9) Goals and planning (15) Shaping knowledge	Social cognitive theory ²⁰
Quinn et al., 2011 ³²	(8) Feedback and monitoring (9) Goals and planning (10) Social support	Transtheoretical model ²¹ Social cognitive theory ²⁰
Ratanawongsa et al., 2014 ²³	(3) Repetition and substitution (8) Feedback and monitoring (14) Identity (12) Self-belief (15) Shaping knowledge	Ecological perspective ³⁸
Reid et al., 2012 ³³	(3) Repetition and substitution (5) Associations (7) Natural consequences (8) Feedback and monitoring (9) Goals and planning (11) Comparison of behaviour (15) Shaping knowledge	Social cognitive theory ²⁰

although the judgement criteria were clearly identified for state of health or behaviour change (body mass index reduction, increase in physical activity, etc.), it remains difficult to capture what was really assessed, what MHApps actually

work on and how.²⁹ what are the behaviour change mechanisms activated by MHApps, what are the underlying theories, how do the different components of MHApps work? Most articles do not provide an understanding of which informational and educational levers are used.⁴⁸ While authors reported a quantification of messages sent or received or connections made,^{26,31} they did not specify the nature of the messages, their relevancy or their adaptability, despite this latter aspect being a factor of effectiveness.⁴⁹ Indeed, it is consistent with the paradigms of the health technology assessment.⁵⁰ These models are mainly used for medical devices, and guidelines exist such as the guide produced by the World Health Organisation⁵⁰ or the European Union guidelines,⁵¹ but they aim to provide a list of criteria for appraising—according to a risk assessment model—the quality, acceptability, opportunity, suitability, use and feasibility of the apps used. In the prevention field, a framework is required to provide an assessment on the way MHApps help to change behaviour. No such framework exists. As an illustration, it is interesting to analyse how the authors characterised the factors of effectiveness/efficacy: ergonomics, adaptability, information sharing and social support, factors of individual motivation and access to the technology. Ergonomics relates to how the tools have to respond to their desirability. Adaptability drives motivation and helps the user maintain the new behaviour in his/her environment. Social support works if it has a precise objective but is variable from one person to another. Motivation and the factors influencing it such as access to the technology allow greater uptake of MHApps as well as enhancing their effectiveness in changing behaviour. Although these factors are interesting, they are not sufficiently studied or analysed to provide a deep understanding of the efficacy mechanisms in prevention MHApps: how do these factors influence the effect of the app? What are the mechanisms involved in this process? On whom do they work? In other words, MHApps were assessed as tools—through an appraisal of their characteristics—and not as behavioural interventions, i.e. through an explanation of the causal inferences between the tool's components, the individual's characteristics and the environment of use.

A need to consider literacy level in the issue of social inequalities

The influence of intervention on social inequalities is a major issue in the prevention field. We have shown above that the issue of social inequalities is poorly assessed and only considered in regard to access to technology, as the number of smartphones is growing rapidly. However, social inequalities include socio-economic background, geographical area but also education, notably literacy. In that respect, Gibbons et al.⁵² propose the creation of a tool for people with limited resources to ensure that all users are readily able to use it and to ensure technical assistance for users. More recently, a review⁵³ showed that the digital divide in eHealth is a serious barrier that contributes greatly to social health inequality and suggests raising awareness of users' literacy level by creating eHealth tools that respect the cultural attributes of users and by encouraging participation among people at risk of social health inequality. This factor should

therefore be taken into account in designing and assessing MHApps.

A need to strengthen the existing assessment model

To address the knowledge gaps in the process evaluation, MHApps should be assessed under the same paradigms as those used to assess face-to-face interventions,^{54,55} taking into account the complexity of prevention interventions, among other things by using underlying theories.^{54,55} This involves better descriptions of the components of MHApps and how they interact and play out in behaviour changes. The use of taxonomies that describe active content, such as the taxonomy of BCTs,^{18,19} should be encouraged as a way to both assess and design MHApps. In the same way, different components of MHApps can have an effect on certain change factors. In light of Michie's behaviour change wheel,⁵⁶ MHApps could influence the motivation, opportunity and capability to change behaviour. To trigger these factors,⁵⁶ various techniques need to be used. However, of 16 categories of BCTs, only four are generally used, all focusing on increasing motivation (shaping knowledge, feedback and monitoring, goals and planning and social support). Yet, we have also shown that apps mainly work on people who are already motivated. This could help explain why the use and effectiveness of MHApps are not maintained over time (under 6 months):^{29,57} they increase existing motivation but remain insufficient to support people's capabilities to change and maintain their behaviours. For example, some BCTs¹⁸ as 'Monitoring of emotional consequences' or 'Avoidance/reducing exposure to cues for the behaviour' could improve capability or opportunity. Hence, they could provide an in-depth support in change behaviour, but they are not reported in MHApps.

Similarly, this would also explain why theory-based MHApps seem to be used more effectively and for longer:^{57–61} these MHApps integrate other behaviour techniques in addition to those linked to motivation and self-knowledge, as is the case in face-to-face prevention strategies. These techniques offer support that goes beyond motivation maintenance, such as coping strategies, cognitive restructuring strategies, environmental restructuring strategies, decision-making help, emotional control techniques, self-incentive, identity framing/reframing, etc.

Regarding the efficacy/effectiveness of MHApps, because of the lack of mechanism exploration (process evaluation), experimental studies are not conclusive in terms of the transferability of these apps beyond experimental conditions. The results are precisely reported but complex to interpret and to use pragmatically. For example, Spring et al.⁶² show that effectiveness stems from a combination of messages. But how does one determine which messages or combination of messages are effective and are to be transferred if the black box of MHApps is not explained? Opening the black box of MHApps, such as all complex health interventions, is not only an heuristic issue but also a transferability and scalability issue, as described in the Medical Research Council guidance.⁵⁴ For all of these reasons, several authors have started to evaluate combined design to assess apps in prevention,⁶³ to

enhance the transferability of the conclusions of efficacy studies.

Limits

The review includes articles from January 2005 to January 2017. A number of articles on MHApps have been published since 2017 but with no significant changes regarding to our conclusions; BCTs and behaviour change wheel are maybe little more used to analyse the conditions of effectiveness, but the most recent articles provide the same conclusions as well as about MHApps effectiveness as about the categories of BCTs involved (average between five and nine BCTs included into goals and planning, feedback and monitoring categories).^{64–68}

To conclude, despite the number of theoretical works on behaviour change interventions, this review has identified a dearth of reporting on mechanisms in experimental studies on the efficacy/effectiveness of MHApps. Yet these studies are used to inform policy prevention. A particular finding, and problem, is that most MHApps have been analysed as tools rather than as prevention strategies. It therefore seems important to combine the paradigms relating to health technology assessment with an evaluation of complex interventions that includes mechanism to improve capability, opportunity and motivation and process evaluation. Thus, MHApps have to be built to complete the health professional's work. Therefore, health professionals and population must be actively involved in developing the intervention theories underpinning the way of actions of MHApps. This is a condition for improved assessments of MHApps in terms of effectiveness, transferability and scalability.

Author statements

Acknowledgements

Pr Rémi Gagnayre, Laboratoire Educations et Pratiques de Santé (LEPS), EA3412, Université Paris13-Sorbonne Paris Cité.

Pr Pierre Lombrail, Laboratoire Educations et Pratiques de Santé (LEPS), EA3412, Université Paris13-Sorbonne Paris Cité.

Authors' contributions

O.A. has made substantial contributions to the conception and design, data collection and analysis, drafting and critical review of the manuscript for important intellectual content. A.V.H., A.V., A.M.F., C.C. have participated in developing the review protocol, data collection and analysis and have contributed to the manuscript. J.P. and L.C. also contributed to this work. They made substantial contributions to the conception or design of the work and the acquisition, analysis and interpretation of data for the work. They drafted the work and revised it critically for important intellectual content. They give final approval of the version to be published. They agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of

any part of the work are appropriately investigated and resolved.

All the authors have read and approved the final manuscript.

Ethical approval

Not required (Scoping review).

Funding

This work was supported by the Institut National de la Santé et de la Recherche Médicale (INSERM) (National institute of health and medical research) 'Contrat de définition-Soutien à la recherche sur les objets connectés' N°2016-15.

Competing interests

None declared.

REFERENCES

- Utilisateurs de smartphone dans le monde 2014-2020 | Prévision [Internet]. Stat., Available from: <https://fr.statista.com/statistiques/574542/utilisateurs-de-smartphone-dans-le-monde-2019/> [cited 2019 Jan 28].
- Commission Européenne. *LIVRE VERT sur la santé mobile*. Bruxelles; 2014. p. 22.
- Aungst TD, Clauson KA, Misra S, Lewis TL, Husain I. How to identify, assess and utilise mobile medical applications in clinical practice. *Int J Clin Pract* 2014 Feb;68(2):155–62.
- Conseil National de l'ordre des Médecins. *Santé connectée. De la e-santé à la santé connectée*. Paris: Le livre blanc du Conseil National de l'Ordre des Médecins; 2015. p. 36.
- Cambon L. Health smart devices and applications? towards a new model of prevention? *Eur J Public Health* 2017;27(3):390–1.
- Wayne N, Perez DF, Kaplan DM, Ritvo P. Health coaching reduces HbA1c in type 2 diabetic patients from a lower-socioeconomic status community: a randomized controlled trial. *J Med Internet Res* 2015;17. e224–e224.
- Norman GJ, Zabinski MF, Adams MA, Rosenberg DE, Yaroch AL, Atienza AA. A review of eHealth interventions for physical activity and dietary behavior change. *Am J Prev Med* 2007;33:336–45. Available from: <https://doi.org/10.1016/j.amepre.2007.05.007>.
- Zahry NR, Cheng Y, Peng W. Content analysis of diet-related mobile apps: a self-regulation perspective. *Health Commun* 2016 Oct 2;31(10):1301–10.
- Petit A, Cambon L. Exploratory study of the implications of research on the use of smart connected devices for prevention: a scoping review. *BMC Public Health* 2016 Dec;16(1):552. Available from: <http://bmcpubhealth.biomedcentral.com/articles/10.1186/s12889-016-3225-4>.
- Azar KMJ, Lesser LI, BY Laing, Stephens J, Aurora MS, Burke LE, et al. Mobile applications for weight management: theory-based content analysis. *Am J Prev Med* 2013 Nov;45(5):583–9.
- Gourlan M, Bernard P, Bortolon C, Romain AJ, Lareyre O, Carayol M, et al. Efficacy of theory-based interventions to promote physical activity. A meta-analysis of randomised controlled trials. *Health Psychol Rev* 2016 Jan 2;10(1):50–66.
- Chen J, Cade JE, Allman-Farinelli M. The most popular smartphone apps for weight loss: a quality assessment. *JMIR MHealth UHealth* 2015 Dec 16;3(4):e104.
- Paillé P, Mucchielli A. *L'analyse qualitative en sciences humaines et sociales*. Paris: A. Colin; 2012.
- Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol* 2005 Feb;8(1):19–32.
- Anderson S, Allen P, Peckham S, Goodwin N. Asking the right questions: scoping studies in the commissioning of research on the organisation and delivery of health services. *Health Res Policy Syst* 2008 Dec;6(1):7. Available from: <http://health-policy-systems.biomedcentral.com/articles/10.1186/1478-4505-6-7>.
- Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 2018 Oct 2;169(7):467–73.
- Babineau J. Product review: covidence (systematic review software). *J Can Health Libr Assoc J Assoc Bibl Santé Can* 2014 Aug 1;35(2):68–71.
- Michie S, Richardson M, Johnston M, Abraham C, Francis J, Hardeman W, et al. The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Ann Behav Med* 2013 Aug;46(1):81–95.
- Cane J, Richardson M, Johnston M, Ladha R, Michie S. From lists of behaviour change techniques (BCTs) to structured hierarchies: comparison of two methods of developing a hierarchy of BCTs. *Br J Health Psychol* 2015 Feb;20(1):130–50.
- Bandura A. *Social foundations of thought and action: a social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall; 1986. p. 617 [Prentice-Hall series in social learning theory].
- Prochaska JO, Velicer WF, Rossi JS, Goldstein MG, Marcus BH, Rakowski W, et al. Stages of change and decisional balance for 12 problem behaviors. *Health Psychol* 1994;13(1):39–46.
- Hartman SJ, Nelson SH, Cadmus-Bertram LA, Patterson RE, Parker BA, Pierce JP. Technology- and phone-based weight loss intervention: pilot RCT in women at elevated breast cancer risk. *Am J Prev Med* 2016 Nov;51(5):714–21.
- Ratanawongsa N, Handley MA, Sarkar U, Quan J, Pfeifer K, Soria C, et al. Diabetes health information technology innovation to improve quality of life for health plan members in urban safety net. *J Ambul Care Manag* 2014;37(2):127–37.
- Alley S, Jennings C, Plotnikoff RC, Vandelanotte C. My Activity Coach - using video-coaching to assist a web-based computer-tailored physical activity intervention: a randomised controlled trial protocol. *BMC Public Health* 2014;14:738. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/25047900>.
- Spring B, Duncan JM, Janke EA, Kozak AT, McFadden HG, DeMott A, et al. Integrating technology into standard weight loss treatment: a randomized controlled trial. *JAMA Intern Med* 2013;173(2):105–11.
- Batch BC, Tyson C, Bagwell J, Corsino L, Intille S, Lin P-H, et al. Weight loss intervention for young adults using mobile technology: design and rationale of a randomized controlled trial - cell Phone Intervention for You (CITY). *Contemp Clin Trials* 2014;37(2):333–41.
- Dennison L, Morrison L, Lloyd S, Phillips D, Stuart B, Williams S, et al. Does brief telephone support improve engagement with a web-based weight management intervention? Randomized controlled trial. *J Med Internet Res* 2014;16(3):e95.
- Nguyen B, Shrewsbury VA, O'Connor J, Steinbeck KS, Hill AJ, Shah S, et al. Two-year outcomes of an adjunctive telephone coaching and electronic contact intervention for adolescent

- weight-loss maintenance: the Loozit randomized controlled trial. *Int J Obes* 2013 Mar;37(3):468–72.
29. Partridge SR, Allman-Farinelli M, McGeechan K, Balestracci K, Wong AT, Hebden L, et al. Process evaluation of TXT2BFI: a multi-component mHealth randomised controlled trial to prevent weight gain in young adults. *Int J Behav Nutr Phys Act* 2016;13(1):7.
 30. Pellegrini CA, Duncan JM, Moller AC, Buscemi J, Sularz A, DeMott A, et al. A smartphone-supported weight loss program: design of the ENGAGED randomized controlled trial. *BMC Public Health* 2012;12:1041.
 31. Svetkey LP, Batch BC, Lin P-H, Intille SS, Corsino L, Tyson CC, et al. Cell phone intervention for you (CITY): a randomized, controlled trial of behavioral weight loss intervention for young adults using mobile technology. *Obesity* 2015;23:2133–41.
 32. Quinn CC, Shardell MD, Terrin ML, Barr EA, Ballew SH, Gruber-Baldini AL. Cluster-randomized trial of a mobile phone personalized behavioral intervention for blood glucose control. *Diabetes Care* 2011;34:1934–42.
 33. Reid RD, Morrin LI, Beaton LJ, Papadakis S, Kocourek J, McDonnell L, et al. Randomized trial of an internet-based computer-tailored expert system for physical activity in patients with heart disease. *Eur J Prev Cardiol* 2012;19(6):1357–64.
 34. Skinner BF. *Science and human behavior*. Free Edition 1953. New York.
 35. Prochaska JO, DiClemente CC, Norcross JC. In search of how people change. Applications to addictive behaviors. *Am Psychol* 1992 Sep;47(9):1102–14.
 36. Witkiewitz K, Marlatt GA. Relapse prevention for alcohol and drug problems: that was Zen, this is Tao. *Am Psychol* 2004;59(4):224–35.
 37. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process* 1991 Dec;50(2):179–211.
 38. Bronfenbrenner U. *The ecology of human development: experiments by nature and design*. Cambridge, Mass: Harvard University Press; 1996. p. 330.
 39. Pagoto S, Schneider K, Jovic M, DeBasse M, Mann D. Evidence-based strategies in weight-loss mobile apps. *Am J Prev Med* 2013 Nov;45(5):576–82.
 40. Cadmus-Bertram L, Nelson SH, Hartman S, Patterson RE, Parker BA, Pierce JP. Randomized trial of a phone- and web-based weight loss program for women at elevated breast cancer risk: the HELP study. *J Behav Med* 2016 Aug;39(4):551–9.
 41. Sangster J, Church J, Haas M, Furber S, Bauman A. A comparison of the cost-effectiveness of two pedometer-based telephone coaching programs for people with cardiac disease. *Heart Lung Circ* 2015;24(5):471–9.
 42. Hughes SL, Seymour RB, Campbell RT. Comparison of two health-promotion programs for older workers. *Am J Public Health* 2011;101(5):883–90.
 43. BY Laing, Mangione CM, Tseng C-H, Leng M, Vaisberg E, Mahida M, et al. Effectiveness of a smartphone application for weight loss compared with usual care in overweight primary care patients: a randomized, controlled trial. *Ann Intern Med* 2014 Nov 18;161(10_Supplement):S5–12.
 44. Peacock OJ, Western MJ, Batterham AM, Stathi A, Standage M, Tapp A, et al. Multidimensional individualised Physical ACTivity (Mi-PACT)—a technology-enabled intervention to promote physical activity in primary care: study protocol for a randomised controlled trial. *Trials* 2015;16: 381–381.
 45. van Berkel J, Boot CRL, Proper KI, Bongers PM, van der Beek AJ. Effectiveness of a worksite mindfulness-based multi-component intervention on lifestyle behaviors. *Int J Behav Nutr Phys Act* 2014;11:9.
 46. Johnson D, Deterding S, Kuhn K-A, Staneva A, Stoyanov S, Hides L. Gamification for health and wellbeing: a systematic review of the literature. *Internet Interv* 2016 Nov;6:89–106.
 47. van Vugt M, de Wit M, Hendriks SH, Roelofsens Y, Bilo HJ, Snoek FJ. Web-based self-management with and without coaching for type 2 diabetes patients in primary care: design of a randomized controlled trial. *BMC Endocr Disord* 2013;13(1):53.
 48. Kivela K, Elo S, Kyngas H, Kaariainen M. The effects of health coaching on adult patients with chronic diseases: a systematic review. *Patient Educ Counsel* 2014;97(2):147–57.
 49. Baumeal A, Muench F. Heuristic evaluation of ehealth interventions: establishing standards that relate to the Therapeutic process perspective. *JMIR Ment Health* 2016;3(1):e5.
 50. World Health Organization, editor. *Evaluation Des technologies de La Sante: Dispositifs Medicaux*. Switzerland: World Health Organization; 2012. p. 41 [Série technique de L'OMS sur les dispositifs médicaux].
 51. European Commission. *Report of the working group on mHealth assessment guidelines*. Digital single market - european commission. 2017. Available from: <https://ec.europa.eu/digital-single-market/en/news/report-working-group-mhealth-assessment-guidelines>.
 52. Gibbons MC, Lowry SZ, Patterson ES. Applying human factors principles to mitigate usability issues related to embedded assumptions in health information technology design. *JMIR Hum Factors* 2014 Dec 18;1(1):e3. Available from: <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4797669/>.
 53. Latulippe K, Hamel C, Giroux D. Social health inequalities and eHealth: a literature review with qualitative synthesis of theoretical and empirical studies. *J Med Internet Res* 2017 Apr 27;19(4):e136.
 54. Moore GF, Audrey S, Barker M, Bond L, Bonell C, Hardeman W, et al. Process evaluation of complex interventions: medical Research Council guidance. *BMJ* 2015 Mar 19;350(mar19 6):h1258–h1258.
 55. Craig P, Petticrew M. Developing and evaluating complex interventions: reflections on the 2008 MRC guidance. *Int J Nurs Stud* 2013 May;50(5):585–7.
 56. Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci* 2011 Dec;6(1):42. Available from: <http://implementationscience.biomedcentral.com/articles/10.1186/1748-5908-6-42>.
 57. Murray E. Web-based interventions for behavior change and self-management: potential, pitfalls, and progress. *Med* 2012;1:e3.
 58. Middelweerd A, van der Laan DM, van Stralen MM, Mollee JS, Stuij M, te Velde SJ, et al. What features do Dutch university students prefer in a smartphone application for promotion of physical activity? A qualitative approach. *Int J Behav Nutr Phys Act* 2015;12:3. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/25889577>.
 59. Ritterband LM, Thorndike FP, Cox DJ, Kovatchev BP, Gonder-Frederick LA. A behavior change model for internet interventions. *Ann Behav Med* 2009 Aug;38(1):18–27.
 60. Tang J, Abraham C, Stamp E, Greaves C. How can weight-loss app designers' best engage and support users? A qualitative investigation. *Br J Health Psychol* 2015 Feb;20(1):151–71.
 61. De Silva MJ, Breuer E, Lee L, Asher L, Chowdhary N, Lund C, et al. Theory of Change: a theory-driven approach to enhance the Medical Research Council's framework for complex interventions. *Trials* 2014 Dec;15(1):267. Available from: <http://trialsjournal.biomedcentral.com/articles/10.1186/1745-6215-15-267>.
 62. Spring B, Schneider K, McFadden HG, Vaughn J, Kozak AT, Smith M, et al. Multiple behavior changes in diet and activity:

- a randomized controlled trial using mobile technology. *Arch Intern Med* 2012 May 28;172(10):789–96. Available from: <http://archinte.jamanetwork.com/article.aspx?doi=10.1001/archinternmed.2012.1044>.
63. Cambon L, Bergman P, Le Faou A, Vincent I, Le Maitre B, Pasquereau A, et al. Study protocol for a pragmatic randomised controlled trial evaluating efficacy of a smoking cessation e-‘Tabac Info Service’: ee-TIS trial. *BMJ Open* 2017 Feb 24;7(2). e013604.
 64. Romeo A, Edney S, Plotnikoff R, Curtis R, Ryan J, Sanders I, et al. Can smartphone apps increase physical activity? Systematic review and meta-analysis. *J Med Internet Res* 2019 Mar 19;21(3). e12053.
 65. Murtagh EM, Barnes AT, McMullen J, Morgan PJ. Mothers and teenage daughters walking to health: using the behaviour change wheel to develop an intervention to improve adolescent girls' physical activity. *Publ Health* 2018 May;158:37–46.
 66. Kebede M, Steenbock B, Helmer SM, Sill J, Möllers T, Pischke CR. Identifying evidence-informed physical activity apps: content analysis. *JMIR mHealth and uHealth* 2018 Dec 18;6(12). e10314.
 67. Enam A, Torres-Bonilla J, Eriksson H. Evidence-based evaluation of eHealth interventions: systematic literature review. *J Med Internet Res* 2018 Nov 23;20(11). e10971.
 68. Eckerstorfer LV, Tanzer NK, Vogrincic-Haselbacher C, Kedia G, Brohmer H, Dinslaken I, et al. Key elements of mHealth interventions to successfully increase physical activity: meta-regression. *JMIR mHealth and uHealth* 2018 Nov 12;6(11). e10076.
 69. Spassova L, Vittore D, Droste DW, Rösch N. Randomised controlled trial to evaluate the efficacy and usability of a computerised phone-based lifestyle coaching system for primary and secondary prevention of stroke. *BMC Neurol* 2016 Dec;16:22.
 70. Taveras EM, McDonald J, O'Brien A, Haines J, Sherry B, Bottino CJ, et al. Healthy Habits, Happy Homes: methods and baseline data of a randomized controlled trial to improve household routines for obesity prevention. *Prev Med* 2012;55(5):418–26.