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An individualized mobile health intervention to promote physical activity in adults with obstructive sleep apnea: An intervention mapping approach

Christophe Latrille^{1,2}, Blandine Chapel³, Nelly Héraud⁴, François Bughin², Maurice Hayot² and Julie Boiché¹

1 EuroMov Digital Health in Motion, University of Montpellier, IMT Mines Ales, Montpellier, France

2 PhyMedExp, University of Montpellier, INSERM, CNRS, CHRU, Montpellier, France

3 Montpellier Research of Management MRM, University of Montpellier, Montpellier, France

4 Direction de la recherche clinique et de l'innovation en santé, Korian SA, Lodève, France

Corresponding author:

Christophe Latrille, University of Montpellier, 700 avenue du Pic Saint-Loup, Montpellier 34090, France.

Email:

christophe.latrille@umontpellier.fr

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Physical activity, behavior change intervention, mHealth, obstructive sleep apnea, intervention mapping

Abstract

Objective:

Combining continuous positive airway pressure with physical activity (PA) might be a promising strategy to treat obstructive sleep apnea (OSA). This article describes how intervention mapping (IM) can guide the development, content, and mechanisms of action of a mobile application to promote PA in adults with OSA.

Methods:

To develop the program, the IM approach was followed. This article presents the first three steps of IM to develop a mixed intervention (with interventionists and a digital application) aiming to: (1) assess patients' health problems and needs in a literature review to determine their expectations and perceived facilitators and barriers to PA behavior change and thus select the determinants of behavior; (2) formulate the expected intervention outcomes and objectives to be met to achieve the overall program goals; and (3) select and implement the behavior change techniques (BCTs) to achieve the change objectives.

Results:

The literature review identified the relevant determinants (e.g., self-efficacy, coping, planning, and habit) of PA behavior using the health action process approach and multiprocess action control. These results were used to specify the program outcomes for PA adapted to physical, psychological, and social parameters. Overall, 11 performance objectives and 30 change objectives were defined. Lastly, BCTs and practical applications were identified.

Conclusions:

The study provides a theoretical and methodological basis for researchers and practitioners given the current paucity of evidence-based PA interventions for adults with OSA. It addresses the lack of BCTs (framing and prompts/cue techniques) and meaningful behavioral determinants (identity and habit) in most interventions.

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Background

Obstructive sleep apnea (OSA) is the repeated complete or partial obstruction of the upper airway during sleep, with brief arousals leading to significant sleep fragmentation. OSA is quite prevalent,¹ showing regional disparities (i.e. 9–38% in Europe and North America and 8.8–24.2% in China)^{2,3} and affecting 4% of middle-aged men and 2% of middle-aged

women,⁴ with prevalence increasing with age.⁵ The 5-year incidence of OSA was estimated at 7% to 11% in middle-aged adults.² The consequences of OSA include cognitive and behavioral deficits such as excessive daytime sleepiness that can affect daily life (e.g. work performance) as well as cardiovascular and metabolic dysfunction.⁶ Moreover, overweight is the most important risk factor for OSA, and around 70% of individuals with OSA are obese.⁷

First-line treatment for OSA is continuous positive airway pressure (CPAP), which has a beneficial effect on breathing during sleep and thus contributes to reducing the OSA severity index (i.e. apnea-hypopnea index or AHI) and excessive daytime sleepiness as well as improving sleep quality. However, long-term CPAP effectiveness remains limited due to low adherence,⁸ while an absence of protective effects against secondary problems such as cardiovascular disease and stroke has been demonstrated.⁹

Previous evidence supports the value of exploring other potential strategies such as introducing physical activity (PA) in complement to CPAP. Indeed, the efficacy of lifestyle changes for OSA has been reported in several meta-analyses.^{10,11} For example, PA has positive effects on AHI in terms of rapid eye movement (REM) and non-REM sleep, subjective sleepiness, cardiometabolic risk factors associated with OSA, and VO_2peak , which is associated with a significant survival benefit.^{11–14} However, individuals with OSA report low levels of PA and have low aerobic capacity.¹¹ Their symptoms may hamper daily life activities in several ways, and PA appears to decrease with increasing AHI.¹⁵ Hence, there is a strong need to combine CPAP and PA for patients with OSA in order to optimize risk factor control and reduce long-term morbimortality.¹¹

Among the systematic reviews and meta-analyses examining the effect of PA in the context of OSA,^{10,11,13,16–23} only one focused on an outcome associated with PA behavior (i.e. number of steps). In this meta-analysis, three randomized controlled trials (RCTs) investigated the effects of physical exercise^{24,25} or a lifestyle intervention²⁶ on PA levels. Only one trial observed increased PA levels after the intervention in patients with OSA and coronary artery disease.²⁵ Since the publication of this meta-analysis, three studies have measured PA levels,^{27–29} but only Black et al.²⁸ and Berger et al.²⁹ evaluated this outcome (i.e. PA questionnaire and accelerometer: unit in counts) before and after the intervention. Both studies showed an increase in PA following the intervention, which then decreased after 12 months.²⁹ Many studies have focused on the effects of PA interventions on the parameters associated with OSA.^{12,24,25,27,28,30–41} By contrast, few have explicitly investigated the effect of a PA intervention on PA behavior itself using objective²⁶ or subjective measurements.²⁹ This limited number of studies integrating the outcome of PA is surprising insofar as CPAP, as the first-line treatment of OSA, has a limited impact on cardiometabolic risk factors, whereas exercise training has a well-documented effect on numerous cardiometabolic risk factors.¹¹

In individuals with chronic disease, several prospective studies have shown a positive association between motivation and PA behavior.^{42–44} Thus, increasing patients' motivation for PA seems pertinent in order to increase their PA level. Studies have also demonstrated that the intention to perform a behavior is necessary^{45–47} but insufficient to initiate the new behavior,^{48,49} thus suggesting that the psychological processes associated with behavior change are manifold. Indeed, many factors contribute to the initiation of PA^{50–56} and its maintenance.^{57–61} In the literature, these constructs have been associated with small to large effect sizes to explain behavior change. Therefore, focusing on the determinants of behavior seems paramount to understanding how to develop more effective PA interventions.^{52,62} In the context of OSA, however, only one study measuring the effect of a PA intervention also assessed a variable associated with motivation²⁷ prior to the intervention. To date, no study has integrated these factors as an outcome both before and after the intervention. These results point to the need for RCTs to investigate the effects of PA interventions on PA behavior itself and its determinants in order to develop more effective interventions.

Bearing this aim in mind, the first critical step is to identify the effective and efficient intervention components to change the behavioral determinants⁶³: for example, a behavior change theory to underpin the intervention and operational constructs to be targeted,⁶⁴ behavior change techniques

(BCTs),⁶⁵ and modes of intervention delivery (e.g. frequency and duration of contact, individual/group delivery). All these components make it possible to build the necessary links between BCTs (i.e. observable, replicable, and irreducible components of an intervention designed to alter or redirect the causal processes that regulate behavior⁶⁵) and the factors associated with motivation (e.g. instrumental attitude representing the expected longterm utility of performing PA), as well as between these factors and PA behavior.^{52,66–71} For instance, if the BCT “information about health consequences” is used to provide scenario-based risk information, it is assumed that this will influence risk perception,⁷² which will in turn prompt people to formulate an intention to engage in PA to reduce the risk.⁷³ Indeed, theoretical knowledge might facilitate the greater inclusion and precision of BCTs in PA interventions, thereby targeting behavior more effectively compared to no-stated-theory interventions. This may even be necessary to derive significant effects.⁷⁴ Theory-based interventions are significantly effective in promoting PA,⁷⁵ and indeed, behavioral theory-based interventions have been recommended in the guidelines for PA interventions in the general population.⁷⁶ These include social cognitive approaches such as the theory of planned behavior,⁷⁷ social cognitive theory,^{78,79} transtheoretical model,⁸⁰ and health action process approach (HAPA)⁷³ in addition to dual process frameworks.⁸¹ To structure the description of content, the v1 taxonomy of BCTs⁶⁵ is known to improve the ability of researchers, practitioners, and policymakers to interpret and replicate effective interventions.⁸² This taxonomy comprises an extensive hierarchical classification of clearly, distinctly (i.e. no overlap, no redundancy), and precisely labeled BCTs. Among the techniques identified as effective in positively impacting the determinants of PA are “feedback on behavior”^{52,66,68} and “self-monitoring of behavior.”^{52,66,68,69,83,84} In practice, however, the duration of self-monitoring with diaries and feedback may be limited by cost and time constraints. Moreover, common traditional interventions include advice from professionals, educational materials, and face-to-face approaches, but these have high resource requirements and are impractical for widespread implementation. ⁸⁵ To overcome these limitations, mobile health (mHealth) interventions may be a promising mode of delivery. ⁸⁶ mHealth interventions refer to “medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices.”⁸⁷ mHealth applications (apps) have unique advantages, as they allow for continuous monitoring that provides the basis for individualized feedback and goal setting.⁸⁸

Even though behavior change interventions are not in their infancy, many evidence gaps remain. Thus, more evidence-based studies are needed to improve the significance of the results. These should describe the intervention content (e.g. BCTs) and application functionalities in sufficient detail to allow for the reproduction of the study and the advancement of this research area.^{62,85,86,89,90} To respond to these needs, the intervention mapping (IM) framework⁹¹ seems relevant. Indeed, this theory-based and evidence-based approach enables interventionists and developers to plan, develop, implement, and evaluate health promotion programs in a systematic way. Moreover, IM ensures that the intervention development deals with the three aspects associated with the dynamics of behavior change.^{92,93} First, the behavior change methods should be chosen by matching them with the determinants that they are likely to impact; second, a precursor to the intervention development should ensure that these determinants predict the relevant behavior; and third, when change methods are applied, the parameters evaluating the effectiveness of the method must be satisfied. Lastly, the IM framework should include evidence-based techniques and behavior change theories.

To promote regular PA behavior in adults with OSA undergoing CPAP treatment, we developed a mixed intervention delivered to patients with OSA in an everyday setting by both

health professionals in a healthcare organization and an mHealth app. For 6 months, multifaceted content is provided either face-to-face or remotely (phone or video) in individual or group sessions. Moreover, patients stay in regular contact with a care manager who can ensure continuous follow-up and refer them to specific professionals (e.g. physician, specialist in adapted PA) if necessary. This article aims to describe how the IM framework was used to develop a theory-based and evidence-based mHealth intervention to promote regular PA in patients with OSA.

Method

Intervention mapping approach

IM is composed of six steps⁹⁴: (1) problem analysis, (2) identification of program outcomes and objectives, (3) selecting theoretical methods and practical strategies for program design, (4) program production, (5) program implementation planning, and (6) evaluation planning. This article presents the first three steps of IM using as an example of our development of a mixed intervention for individuals with OSA (with interventionists and a digital app). Indeed, the first version of the app will be tested in a multicenter clinical RCT to evaluate its acceptability, usability, organizational barriers, and effectiveness. To guide the development process of this intervention, a development group was established consisting of two researchers in psychology and behavior sciences (CL and JB) and an expert in adapted PA with professional experience in respiratory rehabilitation (BC).

Step 1: Problem analysis

This first step of IM is to fully describe the health problem, assess the needs (qualitative or quantitative modalities) of stakeholders, and identify the determinants of the behaviors to be modified individually in the targeted population. In the IM protocol, these determinants are combined with key concepts from social and health psychology (e.g. knowledge, skills, self-efficacy, outcome expectations, perceived social norms) to identify the best theories to explain the problem.

The relevant literature on OSA was systematically reviewed in the PubMed database to identify the studies exploring patient expectations about PA behavior change and the perceived facilitators and barriers for PA engagement. The titles, keywords, and abstracts of papers were screened with terms referring to (1) barrier or facilitator, (2) obstructive sleep apnea, and (3) physical activity. Studies about adults with OSA that explored barriers or facilitators to PA were thus included.

Next, the development group selected the important and modifiable determinants of PA behavior. According to the IM approach, the importance of the determinants relates to their relationship with the current behavior of participants. The development group established the determinants that could be impacted by an intervention, and the importance of these determinants was determined based on group consensus and the available scientific literature. 52,55,56,62,63,65,66,68–71,82,83,95–98

Step 2: Identification of program outcomes and objectives

The second step consists of formulating the expected intervention outcomes and the objectives that need to change in order to achieve the overall goal of the program—that is, for adults with OSA to adopt healthy PA behavior in order to prevent health complications. The performance objectives (PO) formalized the behavior changes that patients with OSA need to implement to achieve the behavioral goals of the program (program outcomes). For each program outcome, one researcher (CL) defined what, in concrete terms, the participants would need to do in the program to reach the desired behavior (POs). Next, the same researcher identified the useful behavioral determinants to effect change with regard to each PO. For example, for the PO “patients learn to perform the physical activity behavior,” the appropriate determinants are “self-efficacy,” “knowledge,” and “skills.” Next, change objectives that state the expected program effects on the determinants were formulated by combining the POs with the changeable determinants of PA behavior. Thus, for “self-efficacy,” which is included in the PO “patients learn to perform the physical activity behavior,” the change objective is to “feel confident in their ability to perform the physical activity behavior without support.” Finally, an IM matrix was built. The matrix specifies the POs, behavioral determinants, and change objectives, which were subsequently validated by the group.

Step 3: Selecting theoretical methods and practical strategies for program design

The third step involves selecting the techniques (or theoretical methods) and determining how to implement them to achieve the formulated change objectives. A BCT is an observable, replicable, and irreducible component of an intervention designed to alter or redirect the causal processes that regulate behavior. For example, “problem-solving” involves analyzing the factors that influence the behavior and selecting the strategies that include overcoming barriers.^{62,65}

For each behavioral determinant and in conjunction with the change objective, one researcher (CL) selected the techniques based on the literature of currently used PA promotion interventions^{52,56,58,66,68–70,83,84,99–118} and the tools to understand them.^{62,65,97,119} For example, to reach the change objective “feel confident in their ability to perform the physical activity behavior without support,” we selected the techniques “instructions about how to perform a behavior,” “demonstration of the behavior,” and “behavioral practice/rehearsal” to change the determinant “self-efficacy.”

The development group chose the conditions under which the methods were shown to be effective and then translated the selected methods into practical strategies. A practical strategy is “a specific application of a theoretical method, adjusted to the intervention setting, tailored to the target population, and applied considering parameters for effective use of the methods.”⁹⁴ For example, the selected method “self-monitoring of behavior” was translated into the practical strategy “every week, data associated with self-monitoring are interpreted and provided to the patient via visual and understandable feedback (text messages).”

Results

Step 1: Problem analysis

Out of 64 papers, the systematic literature review revealed only one study that had conducted semi structured individual interviews with 15 patients with OSA.¹²⁰ This study aimed to explore the aspects of engagement (i.e. expectations, perceived facilitators, and barriers) in PA in overweight adults with OSA. The transcribed data were analyzed according to qualitative content analysis. Two themes reflected the influences on PA engagement: (1) strong enough incentives and (2) facilitators for success and challenges to overcome. Moreover, the conception of the intervention was based on previous work carried out by our team in obese patients, many of whom had OSA.⁹⁸ In this qualitative study, a self-administered questionnaire was completed by 151 patients with chronic diseases (chronic obstructive pulmonary disease, cardiovascular disease, obesity, diabetes, or OSA) to determine the barriers and facilitators of patient adherence to a mobile digital telerehabilitation solution that proposes personalized interventions for patients. The analyses of both qualitative studies revealed that the psychosocial factors that emerged were “risk perception,” “outcome expectancies,” “self-efficacy,” “social support,” “action planning,” and “coping planning.” These factors are part of the HAPA theory.⁷³ Although HAPA has not been used in the context of OSA, it is a promising framework that constitutes a relevant theoretical backdrop for intervention designs to improve PA levels in adults with obesity.⁴² HAPA is a social-cognitive dual-phase model that identifies the determinants for the initiation and maintenance of health behavior (Figure 1). Behavioral intention is a pivotal construct in this model. The model differentiates two distinct phases, each comprising different sets of constructs that determine behavioral enactment. Thus, the motivational phase encompasses outcome expectancies, action self-efficacy, and risk perceptions, whereas the volitional phase includes maintenance and recovery self-efficacy as well as action and coping planning. Furthermore, social support seems to be related to both intention and PA. A meta-analysis that identified the effects of HAPA constructs on PA¹²¹ showed significant effect sizes ranging from 0.13 to 0.43 depending on the construct. These results provide evidence that all HAPA variables are useful to predict PA. Moreover, after applying structural equation modeling, the fit of the HAPA model was deemed satisfactory, explaining 30% of the variance for intention and 18% of the variance for PA in obese adults.⁴² Thus, to develop a PA intervention, the HAPA theory seems relevant.

Finally, several studies have sought to improve our understanding of the translation of intention into PA, particularly its maintenance. Recent studies showed that identity, as an underlying factor of automatic processes, is a moderator of the intention–PA relationship,¹²² and this finding reinforces the need for integrative models that include habit formation and the development of an active identity.¹²³ These factors are part of the multiprocess action control (M-PAC) model.⁹⁷

M-PAC,⁹⁷ which is a recent integrative model used to understand PA, includes findings from several streams of contemporary research in PA, thus bringing together the relevant operational constructs (Figure 2). Schematically, the M-PAC framework is composed of three articulated and interlinked levels. The first level concerns the different phases of behavior and includes intention formation, adoption of action control, and maintenance of action control. The second relates to initiating reflective processes, ongoing reflective processes, regulation

processes, and reflexive processes. Lastly, the third level concerns operational constructs that include, for instance, perceived capacity, behavioral regulation, and habit. Thus, at the top of the M-PAC model, the antecedents of the formation of an intention constitute the initiating reflective processes and correspond to instrumental attitude and perceived capability. M-PAC may serve as an appropriate behavior change theory for the development of interventions aimed at the adoption and maintenance of regular PA in patients with OSA. Indeed, this represents an attempt to integrate research advances regarding PA behavior within a cohesive framework in order to provide a pragmatic structure for practitioners. The M-PAC approach identifies links between BCTs, operational constructs, and phases of behavior change, from the initiation to continuation stages. This model is thus in line with the IM approach: the theory explains how the mechanism of action works, thereby providing insights into why a causal link between the method and behavior change can thus be expected.⁶² Thus, in addition to IM, we used HAPA and M-PAC as theoretical bases to design the intervention.

Step 2: Identification of program outcomes and objectives

The results of the problem analysis were used to specify the program outcomes, POs, and change objectives, which are described below. First, the program outcomes were specified as follows: (1) patients increase their PA level by incorporating aerobic and/or strength-building exercises, 3 to 5 times per week, for a total of at least 150 min, and maintain this practice while performing other daily activities and (2) patients engage in PA in a way that is adapted to their capacities by considering the intensity of the effort with regard to shortness of breath, muscular sensations, and exhaustion.

Second, the performance and change objectives for each of the specific program outcomes were defined. In combination with the HAPA⁷³ and M-PAC⁹⁷ frameworks, the results of the semi-structured individual interviews¹²⁰ were used to define the POs. After specifying these POs, we created a matrix of change objectives by linking the POs to the constructs. To design the program, 11 POs and 30 change objectives were defined (Table 1).

Step 3: Selecting theoretical methods and practical strategies for program design

After identifying the program outcomes, POs, change objectives, and constructs, the theoretical methods and practical strategies were selected. Indeed, the theoretical methods and their translation into practical strategies are the constructs needed to achieve the change objectives. The following paragraphs present this structuration for the 11 POs.

Performance objective 1: Providing health risk and benefit information and recognizing pros and cons.

A recent meta-analysis has highlighted the positive effect of patient education on knowledge, skills, and health behavior.¹⁰⁰ Education interventions usually consist of providing health information about risks/benefits and comparing the advantages and disadvantages of behavior change. The targeted constructs are “risk perception,” “knowledge,” “outcome expectancies,” and “attitude.” Brief messages delivered via mobile device technologies such as short message services have been shown to contribute to behavior change.^{99,101} Furthermore, interventions based on unidirectional messages produce positive effects on behavior change.¹⁰² As research on message frequency and quantity has not yet identified an optimal level,¹⁰³ we chose to send one daily unidirectional message at a time when the user would be available to read the text message (i.e. at 8 am in the morning). The content of the message

concerned the health risks of not performing the PA, the health (bio-psycho-social) benefits of PA behavior, and the links between health and PA. In addition, one 60-min group session (session 1) provided users with the opportunity to learn the “pros and cons” technique to identify the advantages and disadvantages of PA behavior change, hear other points of view, and develop their own representations.

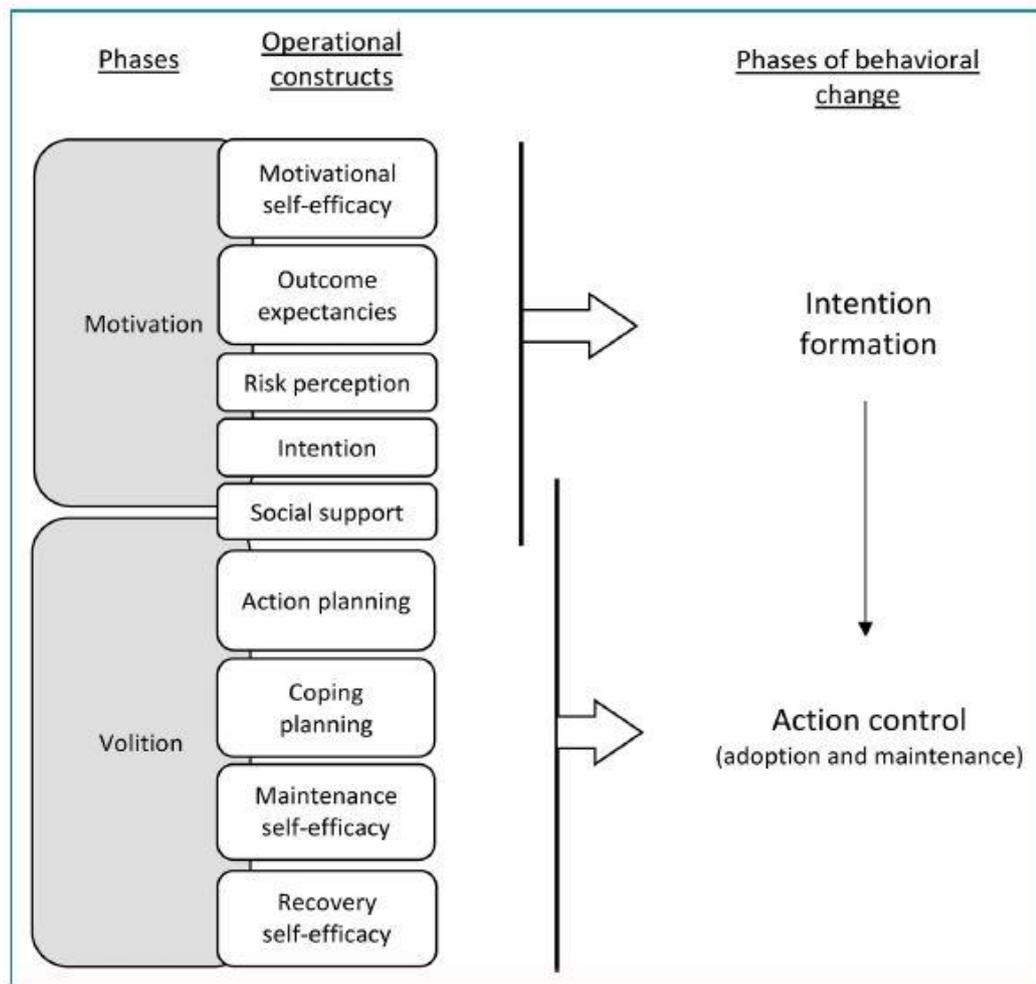


Figure 1. Health action process approach schema (adapted from Parschau, 2014).

Performance objective 2: Providing personal advice and instructions on how to perform the physical activity.

The BCTs related to exercise class attendance and hands-on experiences (i.e. instructions on how to perform the PA, demonstration of the PA, and behavioral practice) to make the new PA behavior achievable. Moreover, prompting preparation for behavior during the intervention may be a good means to positively impact the behavioral determinants. 52 The targeted constructs are “self-efficacy,” “knowledge,” and “skills.” For this purpose, patients have access to adapted exercise videos on the app. These videos are sorted according to the different parts of the body, the type of exercise (strengthening, aerobic, and/or stretching), and the task difficulty. Thus, depending on their choices and goals (associated with a type of exercise), patients can benefit from specific exercises. A group session (session 2) is carried out with a health professional to suggest personalized adaptations of the exercises not anticipated by the app in terms of users’ desires and resources (environmental). At the same time, when patients indicate that they are on a treatment that should be adapted to PA, they are regularly reminded about the instructions for this treatment (e.g. pharmacological support).

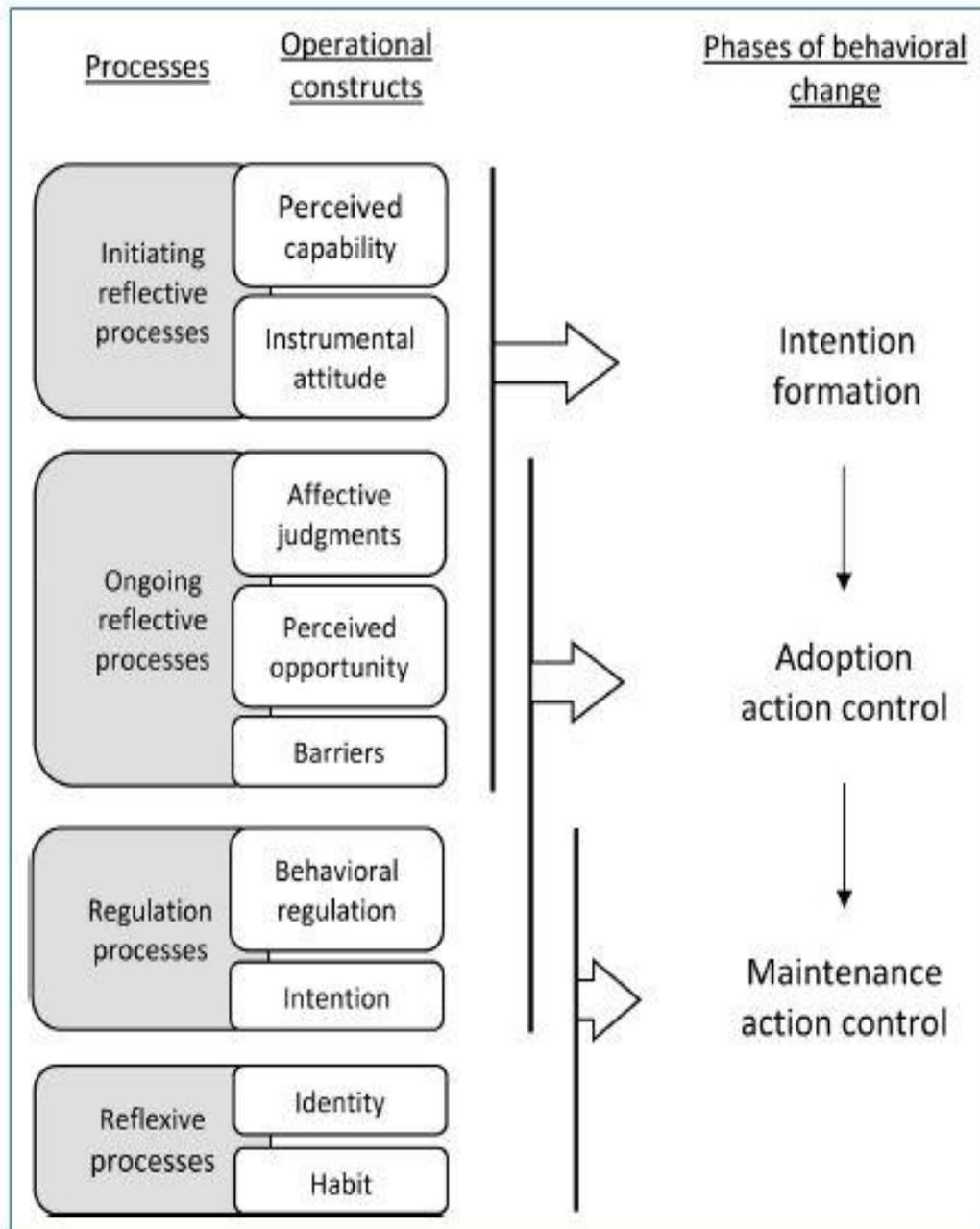


Figure 2. Multiprocess action control schema (adapted from Rhodes, 2017).

Performance objective 3: Providing instructions on how to adapt effort and monitor sensations.

There is evidence that providing graded tasks leads to significant improvements in PA behavior change.^{52,68,83,104} In practice, this technique, alongside the use of sensation rating scales, is linked to more positive affective states during the performance of PA.¹⁰⁵ These can also predict future PA.¹²⁴ The targeted constructs are “self-efficacy” and “skills.” To help patients adapt their efforts in a nonpainful way, the app offers two accompaniments. The first is a step-by-step organized procedure to improve exercise intensity (Table 2) for strengthening exercises, with graded steps defined by the number of exercises, repetitions, and sets. The objective of this support is for patients to perform the recommended 10 exercises with 20 repetitions and 3 sets per exercise. The second accompaniment is a step-by-step

organized procedure to improve planning for the aerobic exercise sessions (Table 3), with stages defined by the number of weekly sessions and the duration of the session. The objective of this support is to help patients achieve the recommended 150 min—up to 250 min—of PA per week with at least three sessions. The progression within the procedures depends on the level of sensations (shortness of breath, pain, muscle difficulty, and/or tiredness) declared (10-point scale) throughout the effort (during and/or at the end). Thus, based on their declarations, patients receive feedback that invites them to progress to the next step, return to the previous step, or stay at the current step. The video exercises offered by the app also depend on the users' perceived sensations. Following their declarations, the patients receive feedback that may suggest more suitable exercises. In session 2, the goal is complementary to that of PO2: to check that patients are performing exercises adapted to their physical capacities and to confirm that they know how to monitor and evaluate their sensations.

Performance objective 4: Providing positive reinforcement.

Positive reinforcement (i.e. nonspecific reward, social reward, and nonspecific incentive⁶⁵) has been identified as a suitable method to change PA.^{66,68,70} Moreover, in combination with mastery experiences and persuasion techniques, this strengthens patients' beliefs in their ability to change.^{62,97} The targeted constructs are “outcome provides incentives and rewards patients' effort and progress through a digital badge system. Once every 2 weeks, feedback reminding users about their last badges prompts them to acknowledge their past success. Mastery experiences (challenging tasks with feedback to indicate capability) are stimulated with “challenges.” This enables them to experiment with PA and encourages the practice or rehearsal of the behavior performance. Finally, an individual session (session 3) is carried out with a health professional to commend their progress and persuade them that they can successfully perform the desired PA.

Performance objective 5: Providing opportunities and environmental facilities.

Restructuring the physical environment is one of the promising BCTs.¹⁰⁶ Adding objects to one's environment has been identified as an effective method to change PA behavior.^{52,83} These techniques are integrated into the opportunity determinant.^{90,97} This construct has been shown to contribute to PA behavior change.^{107,108} Thus, the construct targeted in this PO is “opportunity.” In the intervention, physical opportunity is implemented in relation to the home environment and material resources by providing tips (short digital messages) to help patients restructure their physical environment and by giving them free PA materials.

Performance objective 6: Prompting goal setting.

Health coaching by healthcare professionals along with goal setting brings about positive changes in self-efficacy^{62,109} and PA.^{109–111} The targeted construct is “skills.” To ensure their commitment, patients are asked to choose a PA goal in line with their preferences and capacities. The app asks questions to guide them in identifying what motivates them to increase their PA level. For each motive, proximal (i.e. over 7 consecutive days) and distal (i.e. in 6 months) goals are defined as incentives for immediate action that evolves over time. The goals are defined in terms of PA frequency and duration per week. An individual session (session 4) is carried out with a healthcare professional to improve the patients' ability to define relevant goals.

Table 1. Performance objectives, change objectives, and determinants.

POs and determinant	COs
P01: Patients evaluate the physical activity behavior change with some degree of favor	
Risk perception	CO1: Being aware of their susceptibility to the health risks of obstructive sleep apnea and obesity
Knowledge	CO2: Knowing what good physical activity is and its association with health
Expectancies	CO3: Knowing the benefits of maintaining the recommended physical activity level for their physical, mental, and social health
Attitude	CO4: Recognizing the reasons for wanting or not wanting to change their physical activity behavior
P02: Patients learn to perform the physical activity behavior	
Self-efficacy–action control	CO5: Feeling confident about their ability to perform the physical activity without support
Knowledge	CO6: Knowing how to adapt their medication in the context of physical activity
Skills	CO7: Developing physical activity skills in terms of gesture, posture, and use of equipment
P03: Patients know how to assess and adapt their effort	
Self-efficacy–risk perception	CO8: Feeling confident about their ability to perform the physical activity without fear about bodily sensations or risk of injury
Self-regulatory skills	CO9: Monitoring their bodily sensations (tiredness, shortness of breath, muscle pain, joint pain)
Skills–action control	CO10: Developing physical activity skills to adapt the effort intensity (duration, repetition, and frequency) in coherence with bodily sensations
P04: Patients believe in their ability to change	
Social support	CO11: Receiving support (advice and encouragement) from staff, friends, and/or family for initiating the behavior
Self-efficacy–risk perception	CO12: Feeling confident about their ability to perform the physical activity even when sick or having heart problems
Expectancies	CO13: Feeling positive about the physical activity behavior
Self-efficacy–goal commitment	CO14: Feeling confident about their ability to attain the behavior goal by engaging in mastery experiences
P05: Patients adapt their environment to facilitate their physical activity behavior	
Awareness	CO15: Being aware of the facilitating or hindering effect of the environment
Opportunities	CO16: Understanding opportunities and knowing how to restructure the environment
P06: Patients understand their choice to improve their physical activity behavior	
Goal commitment	CO17: Choosing meaningful short-term and long-term changes
Skills	CO18: Defining a specific, measurable, attainable, relevant, and time-bound goal

POs and determinant	COs
P07: Patients plan how to improve their physical activity behavior	
Action planning	CO19: Planning their physical activity in terms of context, frequency, duration, and intensity
Self-efficacy–self-regulatory skills	CO20: Feeling confident about their ability to prioritize physical activity and make time for it
P08: Patients evaluate their physical activity behavior	
Self-regulatory skills–action control	CO21: Monitoring their physical activity outcomes or behavior
Awareness	CO22: Being aware of discrepancies between their current behavior and previous goals
Action planning	CO23: Being able to review behavior goals and adjust their action planning
P09: Patients develop strategies to overcome difficulties in adopting their physical activity behavior	
Coping planning	CO24: Identifying and anticipating barriers and ways to overcome them
Self-efficacy–recovery	CO25: Feeling able to deal with barriers
Social support	CO26: Receiving support from others to help overcome barriers
P09: Patients develop strategies to overcome difficulties in adopting their physical activity behavior	
Coping planning	CO24: Identifying and anticipating barriers and ways to overcome them
Self-efficacy–recovery	CO25: Feeling able to deal with barriers
Social support	CO26: Receiving support from others to help overcome barriers
P010: Patients take responsibility for their physical activity behavior	
Awareness	CO27: Being aware of their resources and any discrepancies between their current behavior and self-image
Identity	CO28: Developing a new self-identity associated with the physical activity behavior
P011: Patients integrate the habit of their physical activity behavior	
Self-efficacy	CO29: Feeling able to create a physical activity habit
Habit	CO30: Developing a physical activity habit

CO: change objectives; PO: performance objectives.

Table 2. Algorithm for the step-by-step procedure to improve exercise intensity for strengthening exercises.

Step	Number of different exercises	Number of repetitions per exercise	Number of sets
1	5	5	1
2	5	5	2
3	5	10	2
4	5	10	3
5	5	15	2
6	5	15	3
7	5	20	2
8	5	20	3
...
<p>Comment: The patient starts with 5 series and then increases by increments of 5 up to 20 series. Only then are new exercises added one by one.</p>			
...
29	10	20	3

Table 3. Algorithm for the step-by-step procedure to improve planning for the exercise sessions (or exercise intensity for the aerobic exercises).

Step	Session duration (min)	Number of sessions per week	Total exercise per week (min)
1	10	1	10
2	20	1	20
3	10	2	20
4	30	1	30
5	20	2	40
...
12	50	3	150
13	40	4	160
14	30	5	150
Comment: This step may represent a level to be maintained for people whose goal is to perform 150 min per week.			
...
19	63	4	252
20	50	5	250
21	83	3	249

Comment: This step represents a level to be maintained for people whose goal is to perform 250 min per week.

Performance objective 7: Prompting behavior planning.

The BCT known as action planning (as well as implementation intention) has been shown to contribute to significant PA behavior change.^{56,69,112} The constructs targeted in this PO are “self-efficacy” and “action planning.” In the app, patients answer questions to guide them in the development of their action plans. One action plan is created per goal. The action planning process consists of specifying a goal in terms of context (i.e. when, where, and with whom), frequency, duration, and intensity. In individual session 4, the goal is also complementary to that of PO6: helping patients improve their ability to create action plans.

Performance objective 8: Prompting self-monitoring.

Self-monitoring has been identified as a suitable method to change PA behavior.^{83,84,113 115} The targeted constructs are “skills (self-regulatory)” and “action planning.” At the beginning of the intervention, patients synchronize the app with a connected watch. They are asked to wear it throughout the intervention period in their everyday life. Graphs built into the app let them track their daily, weekly, and monthly step counts. In addition, they are also invited to plan the sessions for the coming week (agenda) and then validate what was done in reality (training log). This information is then used to provide automatic feedback on the gap between their goals and actions. In addition to this self-monitoring, patients are invited to monitor their outcomes. To do this, one message is sent to each patient on a monthly basis. A healthcare professional discusses the self-monitoring results with patients and provides feedback. Group session 5 is carried out with a professional to look at any discrepancies between patients’ current behavior and goals. Moreover, during an individual session (session 6), a review of the behavioral goals and action plans is proposed. These sessions aim to teach patients how to use self-monitoring to enrich their reflections and strengthen their decision making.

Performance objective 9: Prompting coping planning.

Coping planning contributes to PA behavior change.^{56,62,68,97, 116,117} The targeted constructs are “self-efficacy,” “social support,” and “action coping.” Using the app, patients are asked to respond to questions once a month about the barriers that they encountered and then to develop a coping plan (i.e. if/then plan). To help them identify solutions, information about antecedents is provided by text messages. In group session 5, the goal is to help them consider solutions through discussions with other patients and feel able to deal with barriers.

Performance objective 10: Developing a physical self-identity.

Self-identity may contribute to behavior change maintenance.^{58,97} The constructs targeted in this PO are “awareness” and “identity.” Therefore, the app provides text messages with content to inform patients about the qualities (values or personal strengths) that enable them to assert their identity as part of a behavior change strategy. An individual session (session 7) is carried out with a healthcare professional to draw the patients’ attention to discrepancies between their current behavior and self-image, to elicit the perceived causes of behavior and suggest alternative explanations, and to help them reinterpret any unhelpful or demoralizing thoughts, feelings, and opinions.

Performance objective 11: Developing a physical activity habit.

Habit may also contribute to behavior change maintenance. 58,97,118 The constructs targeted in this PO are “self-efficacy” and “habit.” Cues are provided by the app in the form of reminders about the PA sessions planned in the agenda. An individual session (session 8) is carried out with a professional to define more relevant stimuli (environmental or social) to prompt or cue the PA behavior at a specific time or place as well as to prompt the rehearsal and repetition of the PA behavior in the same context repeatedly so that the context elicits the behavior.

Discussion

Main findings

This article uses a detailed systematic process to develop a theory-based and evidence-based intervention targeting the adoption and maintenance of PA in patients with OSA. We used the IM framework, which made the process of intervention development and content transparent.

Despite the benefit of PA in the context of OSA,^{10–13,16–41,125} few studies have incorporated an outcome associated with PA level to measure the effect of interventions on the PA behavior itself.^{24–29,40,41} The results are nevertheless heterogeneous, and more RCTs that integrate behavioral outcomes are needed.¹¹ The analysis of PA interventions from 20 experimental studies targeting patients with OSA^{12,24–41,125} indicate that only 2 (10%) studies provided educational content^{12,32} and 3 (15%) included motivational content^{26,27,40} in addition to the PA practice. The only intervention²⁶ to have precisely described its content based on BCTs formed the basis of the latter three studies. This was also the only intervention to have developed its content on the basis of behavior change theories (i.e. social cognitive theory, self-determination theory, and self-regulation constructs). Finally, only one study measuring the effect of a PA intervention also measured a variable associated with motivation prior to the intervention.²⁷ To date, no study has integrated PA-associated variables as an outcome both before and after the intervention.

Following our needs assessment, we identified only one qualitative study that explored the barriers and facilitators to engaging in PA.¹²⁰ However, engaging in PA is a complex and dynamic process involving behavior change. In the context of chronic disease, although PA interventions like practice and/or educational sessions are usually effective in terms of increasing the PA level, highly heterogeneous effects have been observed.⁷⁵ Interestingly, strategies based on cognitive-behavioral learning and social principles may facilitate engagement.¹²⁶ To understand why not all interventions lead to an increase in PA, it seems crucial to explore the role played by the determinants of behavior change and to ascertain which intervention characteristics are associated with more significant results.⁶³ Factors that vary among interventions include the presence and type of behavioral theories underpinning their content,⁶⁴ the BCTs implemented,⁶⁵ and their mode of delivery.⁸³ To better understand the effect of interventions on behavior change in patients with OSA, future RCTs should include interventions based on behavior change theories with their content tailored to the explicit objective of promoting behavior change. They should also evaluate the determinants of behavior before and after the intervention. In addition, more qualitative studies that explore the barriers and facilitators to PA engagement in patients with OSA are needed.

In the field of behavior change, the quality of reporting on intervention content should be improved.¹²⁷ Studies should describe the intervention content (e.g. BCTs) and app features with sufficient detail to enable other researchers to reproduce the study and thereby advance this field of research.^{62,85,86,89,90} Indeed, the results of previous meta-analyses examining the effects of various techniques on the determinants of behavior and/or health-related behavior are limited by the amount of information available regarding both the intervention (i.e. it is often difficult to identify all the techniques implemented) and its level of application.⁶² Thus, the IM protocol, which ensures that all important program objectives are addressed in the intervention and are based on theoretical insights and taxonomies of techniques, offers a relevant method to address this issue.

The type of PA behavior that is beneficial for patients with OSA was shown to be regular PA that is maintained over time.¹²⁸ However, the only study that measured the effect of an intervention on the PA level over the long term (i.e. 12 months) showed that the increase obtained following a 9-month intervention was not maintained in the following months.²⁹ This result was also found in contexts other than OSA.^{129,130} It is therefore important to focus on the processes associated with the maintenance of PA behavior. The M-PAC framework indicates that habit and identity are key factors influencing the long-term uptake of PA. Despite their usefulness for maintaining behavior,^{97,118,131} these two factors have received little attention to date in the context of PA.⁹⁷ Techniques associated with identity and habit formation, framing,^{132,133} and prompts/cues have been seldom used in the context of PA,^{52,134} although they were implemented in our intervention.

To our knowledge, this is the first study to have developed an mHealth PA intervention for patients with OSA. This intervention uses mHealth technology to support the translation of evidence-based methods into practical applications. Indeed, most techniques seem to be supported by these interventions, which enable, for instance, the automatic and continuous monitoring of real-life outcomes.⁸⁸ This offers the possibility of creating individualized and interactive feedback, thus ensuring that PA interventions are better adjusted to the context of everyday life. For example, mHealth could provide good support for habit formation. Indeed, to help people develop exercise habits, intervention efforts should focus on encouraging them to frequently and reliably prepare for and initiate exercise in the same context.¹¹⁸ Furthermore, mHealth interventions⁹⁶ like video counseling¹³⁵ and personalized feedback^{136,137} seem to offer promising perspectives for improving the effect of the interventions.

The app that we created here includes multiple proven techniques that focus on the initiation and maintenance of PA behavior change. We believe that this makes it a unique and promising mHealth intervention to promote PA.

Limitations

The study has several limitations. First, the effectiveness of the intervention has not yet been evaluated by an RCT. Second, PubMed was the only database used in the systematic literature review. Although it is one of the largest available databases, we acknowledge that some useful interventions may have been overlooked. Third, due to time constraints, no focus group was organized during the problem analysis step. Indeed, other researchers who have used the IM protocol have described this as very time consuming, ^{138–140} and the time schedule of the project prevented us from carrying out a focus group. However, the development of this

mHealth intervention was based on previous research carried out by our team in a population of obese patients, many of whom had OSA.⁹⁸ This first experience allowed us to identify levers and understand the needs of these patients regarding the different aspects of a telerehabilitation program. Lastly, we only focused on PA as opposed to including other factors like diet. Further studies are needed to explore more comprehensive interventions for multiple lifestyle changes such as sedentary and diet behaviors.

Conclusions

This article describes the development of an intervention to promote the adoption and maintenance of PA in patients with OSA. The results of the study provide a theoretical and methodological basis for researchers and practitioners. This is especially important given the current paucity of evidence-based PA interventions and their limited content regarding important BCTs (framing and prompts/cues techniques) that address meaningful behavioral determinants (identity and habit). A future paper will report on steps 4, 5, and 6 of the IM framework along with an RCT to indicate whether the intervention is acceptable, usable, well implemented, and effective in improving PA in this population.

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Contributorship:

CL, BC, and JB participated in the intervention development group discussions, created the program functionalities, and developed the intervention map. CL collected the needs assessment data from all described sources and wrote the manuscript. All authors read and critically reviewed the manuscript and approved the final manuscript.

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References

1. Franklin KA and Lindberg E. Obstructive sleep apnea is a common disorder in the population—a review on the epidemiology of sleep apnea. *J Thorac Dis* 2015; 7: 12.
2. Patel SR. Obstructive sleep apnea. *Ann Intern Med* 2019; 171: ITC81.
3. Senaratna CV, Perret JL, Lodge CJ, et al. Prevalence of obstructive sleep apnea in the general population: a systematic review. *Sleep Med Rev* 2017; 34: 70–81.
4. Young T, Palta M, Dempsey J, et al. The occurrence of sleep-disordered breathing among middle-aged adults. *N Engl J Med* 1993; 328: 1230–1235.
5. Young T. Risk factors for obstructive sleep apnea in adults. *JAMA* 2004; 291: 2013.
6. Lévy P, Kohler M, McNicholas WT, et al. Obstructive sleep apnoea syndrome. *Nat Rev Dis Primers* 2015; 1: 15015.
7. Gami AS, Caples SM and Somers VK. Obesity and obstructive sleep apnea. *Endocrinol Metab Clin N Am* 2003; 32: 869–894.
8. Sawyer AM, Gooneratne NS, Marcus CL, et al. A systematic review of CPAP adherence across age groups: clinical and empiric insights for developing CPAP adherence interventions. *Sleep Med Rev* 2011; 15: 343–356.
9. McEvoy RD, Antic NA, Heeley E, et al. CPAP for prevention of cardiovascular events in obstructive sleep apnea. *N Engl J Med* 2016; 375: 919–931.
10. Araghi MH, Chen Y-F, Jagielski A, et al. Effectiveness of lifestyle interventions on obstructive sleep apnea (OSA): systematic review and meta-analysis. *Sleep* 2013; 36: 1553–1562.
11. Mendelson M, Bailly S, Marillier M, et al. Obstructive sleep apnea syndrome, objectively measured physical activity and exercise training interventions: a systematic review and meta-analysis. *Front Neurol* 2018; 9: 73.
12. Bughin F, Desplan M, Mestejanot C, et al. Effects of an individualized exercise training program on severity markers of obstructive sleep apnea syndrome: a randomised controlled trial. *Sleep Med* 2020; 70: 33–42.
13. Bollens B and Reychler G. Efficacy of exercise as a treatment for obstructive sleep apnea syndrome: a systematic review. *Complement Ther Med* 2018; 41: 208–214.
14. Kodama S. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA* 2009; 301: 2024.

15. Chasens ER, Sereika SM, Houze MP, et al. Subjective and objective appraisal of activity in adults with obstructive sleep apnea. *J Aging Res* 2011; 2011: 1–6.
16. Lins-Filho OL, Pedrosa RP, Gomes JML, et al. Effect of exercise training on subjective parameters in patients with obstructive sleep apnea: a systematic review and meta-analysis. *Sleep Med* 2020; 69: 1–7.
17. Edwards BA, Bristow C, O’Driscoll DM, et al. Assessing the impact of diet, exercise and the combination of the two as a treatment for OSA: a systematic review and meta-analysis. *Respirology* 2019; 24: 740–751.
18. Iftikhar IH, Kline CE and Youngstedt SD. Effects of exercise training on sleep apnea: a meta-analysis. *Lung* 2014; 192: 175–184.
19. Torres-Castro R, Vasconcello-Castillo L, Puppo H, et al. Effects of exercise in patients with obstructive sleep apnoea. *Clocks Sleep* 2021; 3: 227–235.
20. Peng J, Yuan Y, Zhao Y, et al. Effects of exercise on patients with obstructive sleep apnea: a systematic review and meta-analysis. *IJERPH* 2022; 19: 10845.
21. Thomasouli M-A, Brady EM, Davies MJ, et al. The impact of diet and lifestyle management strategies for obstructive sleep apnoea in adults: a systematic review and meta-analysis of randomised controlled trials. *Sleep Breath* 2013; 17: 925–935.
22. Andrade Fd and Pedrosa RP. The role of physical exercise in obstructive sleep apnea. *J Bras Pneumol* 2016; 42: 457–464.
23. Stavrou VT, Astara K, Tourlakopoulos KN, et al. Obstructive sleep apnea syndrome: the effect of acute and chronic responses of exercise. *Front Med* 2021; 8: 806924.
24. Kline CE, Crowley EP, Ewing GB, et al. The effect of exercise training on obstructive sleep apnea and sleep quality: a randomized controlled trial. *Sleep* 2011; 34: 1631–1640.
25. Mendelson M, Lyons OD, Yadollahi A, et al. Effects of exercise training on sleep apnoea in patients with coronary artery disease: a randomised trial. *Eur Respir J* 2016; 48: 142–150.
26. Igelström H, Margareta E, Eva L, et al. Tailored behavioral medicine intervention for enhanced physical activity and healthy eating in patients with obstructive sleep apnea syndrome and overweight. *Sleep Breath* 2014; 18: 655–668.
27. Spörndly-Nees S, Åsenlöf P, Lindberg E, et al. Effects on obstructive sleep apnea severity following a tailored behavioral sleep medicine intervention aimed at increased physical activity and sound eating: an 18-month follow-up of a randomized controlled trial. *J Clin Sleep Med* 2020; 16: 705–713.
28. Black JK, Whittaker AC, Tahrani AA, et al. The implementation of a physical activity intervention in adults with obstructive sleep apnoea over the age of 50 years: a feasibility uncontrolled clinical trial. *BMC Sports Sci Med Rehabil* 2020; 12: 46.

29. Berger M, Barthélémy J, Garet M, et al. Longer-term effects of supervised physical activity on obstructive sleep apnea and subsequent health consequences. *Scand J Med Sci Sports* 2021; 31: 1534–1544.
30. Norman JF, Fuchs RH and McElligott M. Exercise training effect on obstructive sleep apnea syndrome. *Sleep Res Online* 2000; 10: 121–129.
31. Loboda D, Stepanik M, Golba A, et al. The beneficial impact of cardiac rehabilitation on obstructive sleep apnea in patients with coronary artery disease. *J Clin Sleep Med* 2021; 17: 403–412.
32. Desplan M, Mercier J, Sabaté M, et al. A comprehensive rehabilitation program improves disease severity in patients with obstructive sleep apnea syndrome: a pilot randomized controlled study. *Sleep Med* 2014; 15: 906–912.
33. Giebelhaus V, Lormes W and Netzer N. Physical exercise as an adjunct therapy in sleep apnea—an open trial. *Sleep Breath* 2000; 4: 5.
34. Sengul YS, Ozalevli S, Oztura I, et al. The effect of exercise on obstructive sleep apnea: a randomized and controlled trial. *Sleep Breath* 2011; 15: 49–56.
35. Servantes DM, Pelcerman A, Salvetti XM, et al. Effects of home-based exercise training for patients with chronic heart failure and sleep apnoea: a randomized comparison of two different programmes. *Clin Rehabil* 2012; 26: 45–57.
36. Ackel-D'Elia C, da Silva AC, Silva RS, et al. Effects of exercise training associated with continuous positive airway pressure treatment in patients with obstructive sleep apnea syndrome. *Sleep Breath* 2012; 16: 723–735.
37. Schütz TCB, Cunha TCA, Moura-Guimaraes T, et al. Comparison of the effects of continuous positive airway pressure, oral appliance and exercise training in obstructive sleep apnea syndrome. *Clinics* 2013; 68: 1168–1174.
38. Cavagnoli DA, Esteves AM, Ackel-D'Elia C, et al. Aerobic exercise does not change C-reactive protein levels in nonobese patients with obstructive sleep apnoea. *Eur J Sport Sci* 2014; 14: S142–S147.
39. Herrick JE, Bliwise DL, Puri S, et al. Strength training and light physical activity reduces the apnea-hypopnea index in institutionalized older adults. *J Am Med Dir Assoc* 2014; 15: 844–846.
40. Igelström H, Åsenlöf P, Emtner M, et al. Improvement in obstructive sleep apnea after a tailored behavioural sleep medicine intervention targeting healthy eating and physical activity: a randomised controlled trial. *Sleep Breath* 2018; 22: 653–661.
41. Barnes M, Goldsworthy UR, Cary BA, et al. A diet and exercise program to improve clinical outcomes in patients with obstructive sleep apnea—a feasibility study. *J Clin Sleep Med* 2009; 05: 409–415.

42. Parschau L, Barz M, Richert J, et al. Physical activity among adults with obesity: testing the health action process approach. *Rehabil Psychol* 2014; 59: 42–49.
43. Plotnikoff RC, Lippke S, Trinh L, et al. Protection motivation theory and the prediction of physical activity among adults with type 1 or type 2 diabetes in a large population sample. *Br J Health Psychol* 2010; 15: 643–661.
44. Scholz U, Sniehotta FF and Schwarzer R. Predicting physical exercise in cardiac rehabilitation: the role of phasespecific self-efficacy beliefs. *J Sport Exerc Psychol* 2005; 27: 135–151.
45. McEachan RRC, Conner M, Taylor NJ, et al. Prospective prediction of health-related behaviours with the theory of planned behaviour: a meta-analysis. *Health Psychol Rev* 2011; 5: 97–144.
46. Rhodes RE and Nigg CR. Advancing physical activity theory: a review and future directions. *Exerc Sport Sci Rev* 2011; 39: 7.
47. Weinstein ND. Misleading tests of health behavior theories. *Ann Behav Med* 2007; 33: 1–10.
48. Rhodes RE and de Bruijn G-J. What predicts intention-behavior discordance? A review of the action control framework. *Exerc Sport Sci Rev* 2013; 41: 201–207.
49. Rhodes RE and Dickau L. Experimental evidence for the intention-behavior relationship in the physical activity domain: a meta-analysis. *Health Psychol* 2012; 31: 724–727.
50. Bélanger-Gravel A, Godin G and Amireault S. A meta-analytic review of the effect of implementation intentions on physical activity. *Health Psychol Rev* 2013; 7: 23–54.
51. Conn VS, Hafdahl AR and Mehr DR. Interventions to increase physical activity among healthy adults: meta-analysis of outcomes. *Am J Public Health* 2011; 101: 751–758.
52. Knittle K, Nurmi J, Crutzen R, et al. How can interventions increase motivation for physical activity? A systematic review and meta-analysis. *Health Psychol Rev* 2018; 12: 211–230.
53. Kwasnicka D, Penseu J, White M, et al. Does planning how to cope with anticipated barriers facilitate health-related behaviour change? A systematic review. *Health Psychol Rev* 2013; 7: 129–145.
54. McEwan D, Harden SM, Zumbo BD, et al. The effectiveness of multi-component goal setting interventions for changing physical activity behaviour: a systematic review and meta-analysis. *Health Psychol Rev* 2016; 10: 67–88.
55. Sheeran P, Wright CE, Avishai A, et al. Self-determination theory interventions for health behavior change: metaanalysis and meta-analytic structural equation modeling of randomized controlled trials. *J Consult Clin Psychol* 2020; 88: 726–737.

56. Zhang C-Q, Zhang R, Schwarzer R, et al. A meta analysis of the health action process approach. *Health Psychol* 2019; 38: 623–637.
57. Gardner B, de Bruijn G-J and Lally P. A systematic review and meta-analysis of applications of the self-report habit index to nutrition and physical activity behaviours. *Ann Behav Med* 2011; 42: 174–187.
58. Kwasnicka D, Dombrowski SU, White M, et al. Theoretical explanations for maintenance of behaviour change: a systematic review of behaviour theories. *Health Psychol Rev* 2016; 10: 277–296.
59. Rebar AL, Dimmock JA, Jackson B, et al. A systematic review of the effects of non-conscious regulatory processes in physical activity. *Health Psychol Rev* 2016; 10: 395–407.
60. Rhodes RE, Kaushal N and Quinlan A. Is physical activity a part of who I am? A review and meta-analysis of identity, schema and physical activity. *Health Psychol Rev* 2016; 10: 204–225.
61. Rhodes RE and de Bruijn G-J. How big is the physical activity intention-behaviour gap? A meta-analysis using the action control framework. *Br J Health Psychol* 2013; 18: 296–309.
62. Kok G, Gottlieb NH, Peters G-JY, et al. A taxonomy of behaviour change methods: an intervention mapping approach. *Health Psychol Rev* 2016; 10: 297–312.
63. Dombrowski SU, Sniehotta FF, Avenell A, et al. Identifying active ingredients in complex behavioural interventions for obese adults with obesity-related co-morbidities or additional risk factors for co-morbidities: a systematic review. *Health Psychol Rev* 2012; 6: 7–32.
64. Avery L, Flynn D, van Wersch A, et al. Changing physical activity behavior in type 2 diabetes: a systematic review and meta-analysis of behavioral interventions. *Diabetes Care* 2012; 35: 2681–2689.
65. Michie S, Richardson M, Johnston M, 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; 46: 81–95.
66. Olander EK, Fletcher H, Williams S, et al. What are the most effective techniques in changing obese individuals' physical activity self-efficacy and behaviour: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act* 2013; 10: 1–15.
67. Gillison FB, Rouse P, Standage M, et al. A meta-analysis of techniques to promote motivation for health behaviour change from a self-determination theory perspective. *Health Psychol Rev* 2019; 13: 110–130.
68. French DP, Olander EK, Chisholm A, et al. Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? A systematic review. *Ann Behav Med* 2014; 48: 225–234.

69. Williams SL and French DP. What are the most effective intervention techniques for changing physical activity self-efficacy and physical activity behaviour—and are they the same? *Health Educ Res* 2011; 26: 308–322.
70. Ntoumanis N, Ng JYY, Prestwich A, et al. A meta-analysis of self-determination theory-informed intervention studies in the health domain: effects on motivation, health behavior, physical, and psychological health. *Health Psychol Rev* 2021; 15: 214–244.
71. McDermott MS, Oliver M, Iverson D, et al. Effective techniques for changing physical activity and healthy eating intentions and behaviour: a systematic review and meta-analysis. *Br J Health Psychol* 2016; 21: 827–841.
72. Kok G. A practical guide to effective behavior change: how to apply theory- and evidence-based behavior change methods in an intervention. *The European Health Psychol* 2014; 16: 156–170.
73. Schwarzer R, Luszczynska A, Ziegelmann JP, et al. Social-cognitive predictors of physical exercise adherence: three longitudinal studies in rehabilitation. *Health Psychol* 2008; 27: S54–S63.
74. McEwan D, Beauchamp MR, Kouvoussis C, et al. Examining the active ingredients of physical activity interventions underpinned by theory versus no stated theory: a meta-analysis. *Health Psychol Rev* 2019; 13: 1–17.
75. Gurlan M, Bernard P, Bortolon C, et al. Efficacy of theorybased interventions to promote physical activity. A meta-analysis of randomised controlled trials. *Health Psychol Rev* 2016; 10: 50–66.
76. King AC, Powell KE, Buchner D, et al. Physical activity guidelines advisory committee. 2018 physical activity guidelines advisory committee scientific report. Washington, DC: U.S. Department of Health and Human Services, 2018.
77. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process* 1991; 50: 179–211.
78. Bandura A. Self-efficacy: toward a unifying theory of behavioral change. *Psychol Rev* 1977; 84: 191–215.
79. Bandura A. Health promotion from the perspective of social cognitive theory. *Psychol Health* 1998; 13: 623–649.
80. Prochaska JO and DiClemente CC. Transtheoretical therapy: toward a more integrative model of change. *Psychother Theory Res Pract* 1982; 19: 276–288.
81. Strack F and Deutsch R. Reflective and impulsive determinants of social behavior. *Pers Soc Psychol Rev* 2004; 8: 220–247.

82. Howlett N, Trivedi D, Troop NA, et al. Are physical activity interventions for healthy inactive adults effective in promoting behavior change and maintenance, and which behavior change techniques are effective? A systematic review and meta-analysis. *Transl Behav Med* 2019; 9: 147–157.
83. Samdal GB, Eide GE, Barth T, et al. Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *Int J Behav Nutr Phys Act* 2017; 14: 42.
84. Murray JM, Brennan SF, French DP, et al. Effectiveness of physical activity interventions in achieving behaviour change maintenance in young and middle aged adults: a systematic review and meta-analysis. *Soc Sci Med* 2017; 192: 125–133.
85. Direito A, Carraça E, Rawstorn J, et al. mHealth technologies to influence physical activity and sedentary behaviors: behavior change techniques, systematic review and meta-analysis of randomized controlled trials. *Ann Behav Med* 2017; 51: 226–239.
86. Fiedler J, Eckert T, Wunsch K, et al. Key facets to build up eHealth and mHealth interventions to enhance physical activity, sedentary behavior and nutrition in healthy subjects— an umbrella review. *BMC Public Health* 2020; 20: 1605.
87. WHO. mHealth: new horizons for health through mobile technologies: second global survey on eHealth, [https:// apps.who.int/iris/handle/10665/44607](https://apps.who.int/iris/handle/10665/44607) (2011, accessed 18 April 2022).
88. Yerrakalva D, Yerrakalva D, Hajna S, et al. Effects of mobile health app interventions on sedentary time, physical activity, and fitness in older adults: systematic review and meta-analysis. *J Med Internet Res* 2019; 21: e14343.
89. Romeo A, Edney S, Plotnikoff R, et al. Can smartphone apps increase physical activity? Systematic review and meta-analysis. *J Med Internet Res* 2019; 21: e12053.
90. Michie S, Ashford S, Sniehotta FF, et al. A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: the CALO-RE taxonomy. *Psychol Health* 2011; 26: 1479–1498.
91. Bartholomew LK, Parcel GS and Kok G. Intervention mapping: a process for developing theory and evidencebased health education programs. *Health Educ Behav* 1998; 25: 545–563.
92. de Bruin M, Crutzen R and Peters G-JY. Everything should be as simple as possible, but this will still be complex: a reply to various commentaries on IPEBA. *Health Psychol Rev* 2015; 9: 38–41.
93. Peters G-JY, deBruinM and CrutzenR. Everything should be as simple as possible, but no simpler: towards a protocol for accumulating evidence regarding the active content of health behaviour change interventions. *Health Psychol Rev* 2015; 9: 1–14.
94. Bartholomew LK, Markham CM, Ruiters RAC, et al. Planning health promotion programs: an intervention mapping approach. 4th ed. San Francisco, CA: Jossey-Bass & Pfeiffer Imprints, Wiley, 2016.

95. Steinmetz H, Knappstein M, Ajzen I, et al. How effective are behavior change interventions based on the theory of planned behavior?: a three-level meta-analysis. *Z Psychol* 2016; 224: 216–233.
96. Nussbaum R, Kelly C, Quinby E, et al. Systematic review of mobile health applications in rehabilitation. *Arch Phys Med Rehabil* 2019; 100: 115–127.
97. Rhodes RE. The evolving understanding of physical activity behavior. *Adv Motiv Sci* 2017; 4: 171–205.
98. Bughin F, Bertrand M, Dupas E, et al.. Development of a digital telerehabilitation solution: analysis of the needs of patients with chronic diseases. *Eur Respir J* 2017; 50: PA3705.
99. Hall AK, Cole-Lewis H and Bernhardt JM. Mobile text messaging for health: a systematic review of reviews. *Annu Rev Public Health* 2015; 36: 393–415.
100. Simonsmeier BA, Flaig M, Simacek T, et al. What sixty years of research says about the effectiveness of patient education on health: a second order meta-analysis. *Health Psychol Rev* 2021; 16: 1–25.
101. Orr JA and King RJ. Mobile phone SMS messages can enhance healthy behaviour: a meta-analysis of randomised controlled trials. *Health Psychol Rev* 2015; 9: 397–416.
102. Arambepola C, Ricci-Cabello I, Manikavasagam P, et al. The impact of automated brief messages promoting lifestyle changes delivered via mobile devices to people with type 2 diabetes: a systematic literature review and meta-analysis of controlled trials. *J Med Internet Res* 2016; 18: e86.
103. Abroms LC, Whittaker R, Free C, et al. Developing and pretesting a text messaging program for health behavior change: recommended steps. *JMIR mHealth uHealth* 2015; 3: e107.
104. Carraça EV, Encantado J, Battista F, et al. Effect of exercise training on psychological outcomes in adults with overweight or obesity: a systematic review and meta-analysis. *Obes Rev* 2021; 22: 1–18.
105. Ekkekakis P, Hargreaves EA and Parfitt G. Invited guest editorial: envisioning the next fifty years of research on the exercise–affect relationship. *Psychol Sport Exerc* 2013; 14: 751–758.
106. Gardner B, Smith L, Lorencatto F, et al. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. *Health Psychol Rev* 2016; 10: 89–112.
107. Howlett N, Schulz J, Trivedi D, et al. A prospective study exploring the construct and predictive validity of the COM-B model for physical activity. *J Health Psychol* 2019; 24: 1378–1391.

108. Willmott TJ, Pang B and Rundle-Thiele S. Capability, opportunity, and motivation: an across contexts empirical examination of the COM-B model. *BMC Public Health* 2021; 21: 1014.
109. Kivelä K, Elo S, Kyngäs H, et al. The effects of health coaching on adult patients with chronic diseases: a systematic review. *Patient Educ Couns* 2014; 97: 147–157.
110. Oliveira JS, Sherrington C, Amorim AB, et al. What is the effect of health coaching on physical activity participation in people aged 60 years and over? A systematic review of randomised controlled trials. *Br J Sports Med* 2017; 51: 1425–1432.
111. An S and Song R. Effects of health coaching on behavioral modification among adults with cardiovascular risk factors: systematic review and meta-analysis. *Patient Educ Couns* 2020; 103: 2029–2038.
112. Carvalho TdC, Soares AF, Climaco DCS, et al. Correlation of lung function and respiratory muscle strength with functional exercise capacity in obese individuals with obstructive sleep apnea syndrome. *J Bras Pneumol* 2018; 44: 279–284.
113. Michie S, Fixsen D, Grimshaw JM, et al. Specifying and reporting complex behaviour change interventions: the need for a scientific method. *Implement Sci* 2009; 4: 40, 1748–5908-4–40.
114. Teixeira PJ, Carraça EV, Marques MM, et al. Successful behavior change in obesity interventions in adults: a systematic review of self-regulation mediators. *BMC Med* 2015; 13: 84.
115. de Vries HJ, Kooiman TJM, van Ittersum MW, et al. Do activity monitors increase physical activity in adults with overweight or obesity? A systematic review and metaanalysis: do activity monitors increase physical activity? *Obesity* 2016; 24: 2078–2091.
116. Avery L, Flynn D, Dombrowski SU, et al. Successful behavioural strategies to increase physical activity and improve glucose control in adults with type 2 diabetes. *Diabet Med* 2015; 32: 1058–1062.
117. Seo D-C and Sa J. A meta-analysis of psycho-behavioral obesity interventions among US multiethnic and minority adults. *Prev Med* 2008; 47: 573–582.
118. Rebar AL, Gardner B and Verplanken B. Habit in exercise behavior. In: Tenenbaum G and Eklund RC (eds) *Handbook of sport psychology*. Hoboken, NJ: États-Unis, Wiley, 2020, pp. 986–998.
119. Hardcastle SJ, Fortier M, Blake N, et al. Identifying contentbased and relational techniques to change behaviour in motivational interviewing. *Health Psychol Rev* 2017; 11: 1–16.
120. Igelström H, Martin C, Emtner M, et al. Physical activity in sleep apnea and obesity-personal incentives, challenges, and facilitators for success. *Behav Sleep Med* 2012; 10: 122–137.

121. Choi Y, Yang SJ and Song HY. Effects of the variables related to the health action process approach model on physical activity: a systematic literature review and meta-analysis. *J Korean Acad Community Health Nurs* 2018; 29: 359.
122. Rhodes RE, Cox A and Sayar R. What predicts the physical activity intention–behavior gap? A systematic review. *Ann Behav Med* 2022; 56: 1–20.
123. Kwan MYW, Brown DMY, Dutta P, et al. Application of the multi-process action control model to predict physical activity during late adolescence. *J Sport Exerc Psychol* 2022; 44: 35–41.
124. Rhodes RE and Kates A. Can the affective response to exercise predict future motives and physical activity behavior? A systematic review of published evidence. *Ann Behav Med* 2015; 49: 715–731.
125. Jurado-García A, Molina-Recio G, Feu-Collado N, et al. Effect of a graduated walking program on the severity of obstructive sleep apnea syndrome. A randomized clinical trial. *IJERPH* 2020; 17: 6334.
126. Hellénus M-L, Alton V, Eckerlund I, et al. Methods of promoting physical activity a systematic review. *Swedish Council Health Technol Assess (SBU Yellow Report)* 2007; 181: 1–14.
127. Albrecht L, Archibald M, Arseneau D, et al. Development of a checklist to assess the quality of reporting of knowledge translation interventions using the Workgroup for Intervention Development and Evaluation Research (WIDER) recommendations. *Implement Sci* 2013; 8: 52.
128. Berger M, Bayon V, Hirotsu C, et al. Place de l'activité physique dans la prise en charge du syndrome d'apnées obstructives du sommeil : état des lieux et recommandations. *Méd Sommeil* 2020; 17: 87–99.
129. Avenell A, Broom J, Brown T, et al. Systematic review of the long-term effects and economic consequences of treatments for obesity and implications for health improvement. *Health Technol Assess* 2004; 8: 21.
130. Saunders TJ, Dechman G, Hernandez P, et al. Distinct trajectories of physical activity among patients with COPD during and after pulmonary rehabilitation. *J Chronic Obstr Pulm Dis* 2015; 12: 539–545.
131. Lally P and Gardner B. Promoting habit formation. *Health Psychol Rev* 2013; 7: S137–S158.
132. Larsen KD, Shrestha S and Jones K. Effects of cognitive restructuring techniques on physical activity in older adults. *J Public Health Issues Pract* 2019; 3: 141.
133. van 't Riet J, Ruiters RAC, Werrij MQ, et al. Investigating message-framing effects in the context of a tailored intervention promoting physical activity. *Health Educ Res* 2010; 25: 343–354.

134. Lin H, Xu D, Yang M, et al. Behaviour change techniques that constitute effective planning interventions to improve physical activity and diet behaviour for people with chronic conditions: a systematic review. *BMJ Open* 2022; 12: e058229.
135. Byaruhanga J, Atorkey P, McLaughlin M, et al. Effectiveness of individual real-time video counseling on smoking, nutrition, alcohol, physical activity, and obesity health risks: systematic review. *J Med Internet Res* 2020; 22: e18621.
136. Polonsky WH and Fisher L. When does personalized feedback make a difference? A narrative review of recent findings and their implications for promoting better diabetes self-care. *Curr Diab Rep* 2015; 15: 50.
137. Braakhuis H, Berger M and Bussmann J. Effectiveness of healthcare interventions using objective feedback on physical activity: a systematic review and meta-analysis. *J Rehabil Med* 2019; 51: 151–159.
138. Plaete J, De Bourdeaudhuij I, Verloigne M, et al. A selfregulation eHealth intervention to increase healthy behavior through general practice: protocol and systematic development. *JMIR Res Protoc* 2015; 4: e141.
139. Moreau M, Gagnon M-P and Boudreau F. Development of a fully automated, web-based, tailored intervention promoting regular physical activity among insufficiently active adults with type 2 diabetes: integrating the I-change model, selfdetermination theory, and motivational interviewing components. *JMIR Res Protoc* 2015; 4: e25.
140. Scheerman JFM, van Empelen P, van Loveren C, et al. A mobile app (WhiteTeeth) to promote good oral health behavior among Dutch adolescents with fixed orthodontic appliances: intervention mapping approach. *JMIR Mhealth Uhealth* 2018; 6: e163.