Design framework for the development of tailored behavior change technologies

Case study of a motivational mobile application for self-management of chronic low back pain

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Today, so-called persuasive or motivational technologies are developing, which refer to technologies, applications or services designed to induce changes in attitudes and behavior in those who use them. This is the subject of research in Human-Computer Interaction in connection with theories from psychology related, for example, to behavior change or motivation. Research on these technologies suggests that in order to encourage long-term adherence, these "virtual coaches" need to be personalized and/or tailored according to the individual characteristics of the users (stage of behavior change, motivations, preferences, barriers). For example, according to the Self-Determination Theory (SDT), an individual can present different forms of motivation, more or less effective. The idea is to be able to identify the forms of motivation present in users in order to propose services to reinforce or develop them. The use of such systems in the field of health has the potential to induce and reinforce health behaviors that are sometimes difficult to establish by health professionals. Providing daily, personalized care

represents a considerable human and financial cost for health professionals. A mobile application has the advantage of being able to deal with these constraints. The computer coach is designed with and for patients suffering from chronic low back pain. The aim is to help them manage their condition, particularly with regard to their pain and the practice of regular physical activity. The work presented presents an innovative design approach, combining user-centered methodologies and psychological theories, which we detail through a research phase and a design phase. Currently, a first version of the application has been developed and is being tested.

CCS CONCEPTS • Human-centered computing • User studies • User models

Additional Keywords and Phrases: mHealth, user-centered design, motivational profiles, chronic low back pain

Introduction

Web-based health (eHealth) or mobile health (mHealth) applications have great potential to improve the health of the population and the efficiency and reach of health care services [1]. From this perspective, many applications are proposed on the market, but recent evaluations have revealed that the vast majority of them are not based on a scientific framework [2]. Thus, the informatics literature emphasizes the need for systems that draw on models and theories from the humanities to support health behavior change [1][3].

Fogg was one of the initiators of research into so-called persuasive technologies and their application to health [4]. His research has focused on the use of technology to influence and positively change people's behavior based on persuasive strategies identified in social psychology. Recently, Oinas-Kukkonen has developed the concept of behavior change support systems (BCSS) in health [5] and proposed the Persuasive System Design (PSD) model [6] to better frame research and design activities in this area. Research into HCI to reinforce or even provoke user motivation, commitment or behavior has led to the emergence of new concepts such as behavior change techniques [7], nudges [8] or gamification [9]. Numerous ethical questions have arisen regarding the use of persuasive technologies and their potential consequences on users [10][11]. Today, models are proposed for the evaluation and design of technologies to optimize user engagement, motivation and well-being and to differentiate between unhealthy positive experiences (e.g. technology addiction) and healthy ones [13].

The use of digital interventions for people with chronic diseases such as low back pain has already been the subject of several studies. These have been shown to have a significant positive effect on disease monitoring, self-reporting, education, promotion of physical activity [14][15], and improvement in short-term pain and disability for patients with chronic low back pain [16]. Recently, the Self-Back self-management support application for low back pain was evaluated in a randomized controlled trial [17]. The results showed an improvement in pain-related disability at 3 months but this was too small and of uncertain clinical significance. Although there are many applications available for self-management of low back pain, their effectiveness in improving patient outcomes is rarely empirically evaluated [18]. Recent evaluations of commercially available applications have revealed that the vast majority are not based on a scientific framework [9]. Thus, the informatics literature emphasizes the need for personalized and behavioral science-based systems to support health behavior change [1][3].

In this work, we propose a new design framework by taking as a case study the design of a personalized coaching mobile application supporting the change of behavior of low back pain patients towards physical activity, and more generally the management of their pathology. The aim is to design personalized human-machine interactions based on theories and models from psychology.

Related work

Michie et al [19] have proposed a design framework called "Behaviour change wheel" for the design of interactive behaviour change systems based on the COM-B model. In this model, behavior is predicted by three interacting factors: ability, opportunity, and motivation. This design framework identifies the functions and associated policies that can support these factors. After selecting the intervention function(s) most likely to be

effective in changing a target behavior, the authors suggest linking them to specific behavior change techniques [20]. Other design frameworks have been proposed to frame the development of so-called "positive" interactive technologies [21]. For example, METUX is a design framework for well-being technologies based on Self-Determination Theory [22][23]. This framework guides the design and evaluation of interactive technologies aimed at facilitating engagement, motivation, and user experience by focusing on meeting the needs identified by SDT: autonomy, competence, and affiliation. These needs must be considered across six "spheres": application adoption, human-machine interaction with the application, tasks performed with the application, resulting behaviors, the user's life, and society more generally.

In terms of mobile apps for pain management, these are considered convenient and valuable by patients and healthcare professionals [24]. However, the generalizability of the results is limited due to the heterogeneity of the participants included in the trials and the intervention duration [25]. In the case of low back pain management, most digital interventions do not show significant beneficial effects [26]. Nevertheless, evaluation of the content of these apps identified several relevant categories: pain educational material, general wellness activities, exercise tips and goals, electronic community, and patient stories. Patients' opinions regarding barriers to adherence to a home exercise program and expectations for new technologies were also collected [27]. The results suggest that adherence to home exercise programs could be facilitated by increasing the attractiveness of the programs (scalable programs, gamification, accessibility in the environment), enhancing patient performance (offering a model such as demonstration videos, providing feedback), and promoting a sense of support. On the other hand, it seems relevant to consider the stages of behavior change of low back pain patients in order to further optimize the feedback strategy used [28]. Finally, a clear and intuitive interface is essential for patient adherence, which requires a long-term treatment such as that for low back pain [29].

The objective of our work is to evaluate the effectiveness of a mobile application (that we co-designed with health professionals and patients) through a Randomized Controlled Trial with a cohort of patients. To design the mobile application, we chose to adopt a user-centered design approach. This approach is one of the International Organization for Standardization (ISO) standards that specify requirements and recommendations for the principles and activities involved in this process. According to the ISO 9241-210 standard, this approach is defined by five application and implementation criteria: (1) The upstream consideration of users, their tasks and their environment, (2) the active participation of users, guaranteeing the fidelity of the needs and requirements related to their tasks, (3) the appropriate distribution of functions between users and technology, (4) the iteration of design solutions, until the needs and requirements expressed by the users are satisfied, and (5) the intervention of a multidisciplinary design team, aiming at an optimal user experience. In this paper, we present the state of progress of the work within the framework of this design methodology (Figure 1) through two axes: the user research phase, which aims to respond to criteria (1) and (2) stated above, and the design phase, which considers criteria (3) and (4). Note that criterion (5) is an integral part of both phases.

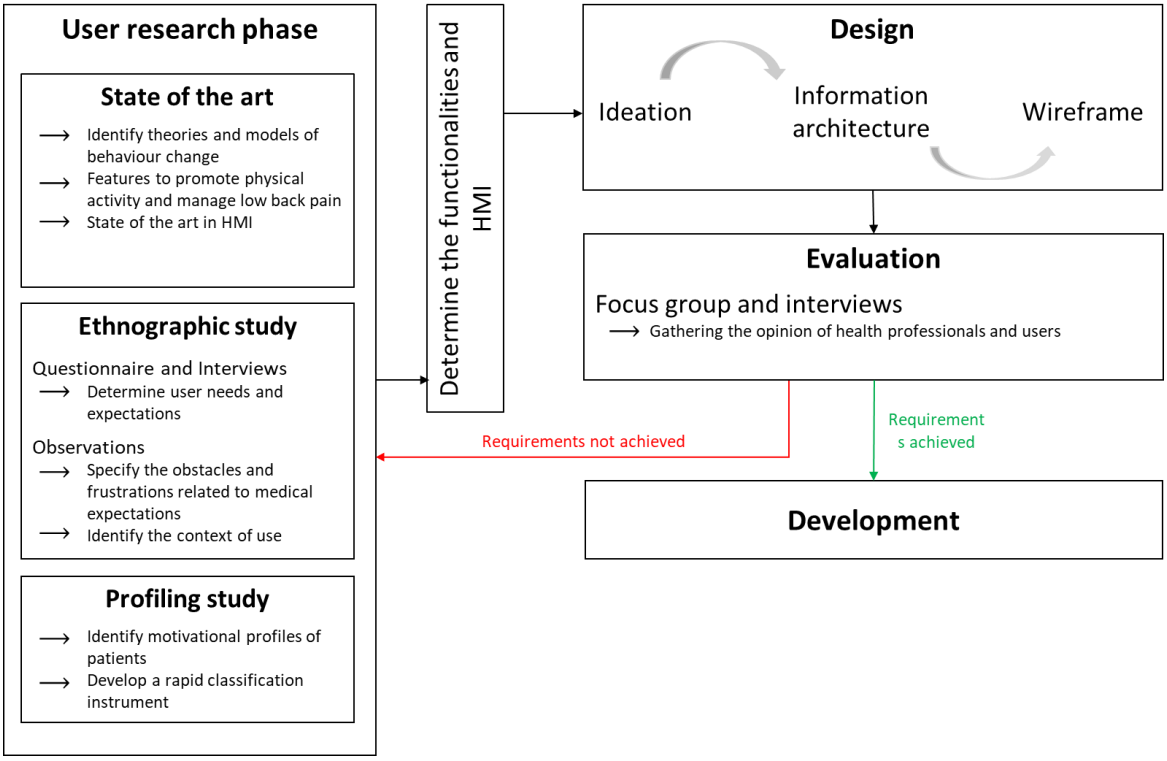

Figure 1: User-centered design phases of the mobile application for low back pain management

1 USER RESEARCH PHASE

In the user-centered approach, the research phase aims to specify the needs and expectations of the end users. The different works that make up this phase aim to identify the solutions proposed in the literature, the context of use, the existing frustrations and problems and the mental models of the targeted users. To meet these objectives, we conducted three studies, which we detail in this section.

1.1 State of the art

An initial literature review enabled us to summarize the strategies and techniques used to persuade and motivate users, as well as the factors that can impact on their behavioral change. For the design of our intervention, we based ourselves on the HAPA (Health Action Process Approach) model [30] because of its approach, which is adapted to the health context, and because it considers other determinants in addition to intention in order to support behavior change. The HAPA model suggests that the adoption, initiation and maintenance of health behaviors should be explicitly conceived as a process that includes at least a motivational and a volitional phase. The former corresponds to the construction of the intention to change behavior, mainly influenced by risk perception and outcome expectations. The second phase is subdivided into a planning phase, an action phase and a maintenance phase. It is important to note that perceived self-efficacy, as well as barriers and resources play a crucial role in all phases of the model. Several recent studies have attempted to list these barriers and resources to physical activity in chronic low back pain [27][31][32]. Boutevillain proposes to divide them into 3 categories: Physical, Psychological and Socio-environmental (Table 1).

Table 1: Summary of low back pain patients' barriers and resources to physical activity [27][31][32]

	Physical	Psychological	Socio-environmental
Barriers	Pain Co-morbidities	Lack of motivation Lack of perceived benefits Fears and false beliefs Lack of knowledge Depression	Lack of time False recommendations Poor organization Profession
Resources	Back support (ex: lumbar belt)	Will/Desire Self-esteem	Supervision by a health professional Monitoring of the PA Group practice

Because of its adaptive and everyday nature, a mobile application can address certain socio-environmental barriers, but it is also important to consider psychological barriers to promote behavioral change. Moreover, we can link some of the psychological barriers and resources identified in the case of low back pain with the factors described in the HAPA model influencing behavioral intention. The barrier "lack of perceived benefits" could be related to "outcome expectations", while "lack of knowledge" or "false beliefs" could modify patients' "risk perception". The resource "self-esteem" can be reinforced by the feeling of self-efficacy impacting throughout the process of behavior change. Another psychological barrier more specific to low back pain is highlighted here: "depression". According to the HAPA model, all these factors play a role during the motivational phase, which could explain the presence of the "lack of motivation" barrier. Finally, this research allows us to identify the psychological factors that impact the behavior change process of low back pain patients.

Regarding the computer science literature review, Oinas-Kukkonen et al [6] proposed a categorization of the main persuasive strategies to be applied when designing persuasive systems, initially proposed by Fogg. This taxonomy distinguishes between two often confused strategies: personalization and tailoring. Personalization consists of offering content or services tailored to the individual preferences of the user. Tailoring proposes an adaptation according to various factors potentially relevant to a group of several users. These strategies are widely recommended in the literature, especially for the design of e-coaching systems for physical activity [33][34][35]. In 2014, researchers proposed seven key tailoring concepts for real-time physical activity training systems [36]. The most used concepts are feedback, goal setting, user targeting and inter-human interaction. Concepts such as self-learning, context awareness and adaptation are less used [37]. There are therefore many opportunities to design a system tailored to a user or a group of users. Tailoring has the advantage of being able to propose an automatic adaptation based only on the data that identifies the user's profile and the group to which he belongs. These profiles must be based on relevant factors to support users in their process of changing their behavior.

1.2 Ethnographic study

The ethnographic study is a fieldwork with users to determine their expectations and needs. We conducted two preliminary interviews and an exploratory questionnaire to collect a set of qualitative data on the opinions of 110 patients towards a mobile application for the self-management of low back pain. The questionnaire allowed us to highlight the main functionalities expected by users, which are personalized physical activity exercises and pain management advice. Also, our participants reported a low interest in sharing and connecting with peers.

Through the interviews, we determined the specific needs of certain user profiles. Two objectives emerged repeatedly during the interviews: to increase knowledge through clear explanations and to have a long-term follow-up. Another common obstacle is the lack of information or interest in existing mobile applications. On a more individual level, other expectations emerged such as increased motivation, encouragement, diversity in physical exercise, interactivity and a high degree of personalization or even real-time monitoring. The other obstacles presented were the consequence of the lack of knowledge and sometimes divergent explanations in the medical environment, but also the impact of the disease on the patient's social life.

In order to specify the brakes and frustrations linked to medical expectations, we carried out observations of patients within a short therapeutic and multidisciplinary training program (1.5day) offered by the Cochin Hospital. These observations allowed us to see the application of the four main steps in the treatment of low back pain: (1) increasing knowledge in order to break down false beliefs, (2) regular physical activity, (3) counselling on daily movements and postures, and (4) implementation of pain management techniques (CBT). Regarding the patients' experience during the workshop, it was initially rather negative, as the consequences of the disease were still very predominant among the participants. However, this experience quickly changed for the better during the workshop thanks to the personalized feedback, the adaptation of the physical exercises to their specific needs, the clear and complete explanations and, above all, the follow-up offered.

1.3 Profiling study

With the aim of tailoring the intervention, we wanted to determine whether motivational profiles of low back pain patients can be defined in order to offer personalized and automated care through the mobile application. In this section we present a summary of our previously published study [38]. In his thesis, Dekkers [39] proposed a method for profiling orthopedic patients based on clinical, psychological and communication characteristics with the aim of providing tailored healthcare services. This was based on the results of patient data analysis rather than on the experience of healthcare professionals. This work resulted in specific design guidelines for three patient profiles for the development of digital applications for them [40]. In the field of physical activity, several studies have already proposed motivational profiles [41][42] based on self-determination theory (SDT) [22][23]. This theory distinguishes between intrinsic (or self-determined) motivation, extrinsic (or controlled) motivation and amotivation (or lack of motivation). Self-determined motivation implies that the individual feels completely free to make choices, whereas controlled motivation implies that one's actions are influenced and guided by external pressures [22]. Thus, SDT considers that there are different forms of behavioral regulation that can be represented on a continuum of self-determination ranging from amotivation to intrinsic motivation. The results of work on motivational profiles based on SDT have helped to initiate effective strategies for developing exercise adherence by focusing on the types of motivations of individuals [41][42]. Although several studies have attempted to identify profiles in order to personalize support, none to our knowledge has proposed motivational or psychological profiles related to the process of behavior change in patients suffering from chronic low back pain.

For this work, we used questionnaires completed by 193 participants in an e-cohort of low back pain patients. First, we analyzed some socio-demographic data in order to characterize our sample with respect to the general population of low back pain patients: age, gender, professional status and duration of low back pain. In addition, we selected several scales to measure the psychological factors identified in the literature review (Table 1) that potentially impact the process of patient behavior change: sense of self-efficacy (FC-CPSES) [43], level of depression (PHQ-9) [44], motivation (EMAPS) [45], and fears and beliefs (FABQ-AP) [46] towards patients' physical activity. Each of the scales was analyzed following the recommendations presented in the literature. For the motivational characteristics, we continued the analyses with the aim of identifying homogeneous groups of patients. Cluster analysis consists of four steps: (1) selection of cluster variables, (2) decision on the clustering procedure, (3) determination of the number of clusters, and (4) validation of the cluster solution [47]. To start with, we identified 10 variables to be included in the clustering analysis. These ten variables are: the chronic pain-specific self-efficacy score, the depression score, the 6 scores of the different types of motivation identified by the SDT and the fear and belief score towards physical activity. For the clustering procedure we used the Hierarchical Ascending Classification (HAC) which allows to visualize the progressive clustering of the data. The appropriate number of clusters can then be determined based on the examination of the dendrogram and the agglomeration coefficient. Finally, a one-factor multivariate analysis of variance (manova) was conducted with the cluster as the independent variable and the motivational variables as the dependent variables to analyze the motivational characteristics of each group.

This methodology allowed us to identify 4 profiles: (1) Unmotivated characterized by the lowest motivation score and the highest amotivation score towards physical activity (i.e. they don't understand why it is useful), (2) Cautious with low motivation and having the strongest fears and beliefs towards physical activity, (3) Depressed with good intrinsic motivation but also a high level of depressive symptoms, and (4) Confident also showing good intrinsic motivation, having the highest self-efficacy and the lowest depression score. Such profiles can allow us to tailored the application to support them in their behavior change process.

The second step was to determine a quick classification tool to classify patients into one of these 4 profiles, as the set of questionnaires used represent too many questions which could be a barrier to the acceptability of the mobile application. The Classification and Regression Tree (CART) methodology [48] is a supervised machine learning method for building a decision tree for future cases [49]. As we had only collected one dataset, we tested the resulting decision tree only on the existing dataset (i.e. the training data) and not on new data. Therefore, we present this decision tree only as a preliminary selection tool. Six decision rules are used to assign patients to the appropriate group. In the current dataset, the instrument achieved an accuracy of 82% (95% CI: [75%, 89%]). It is slightly less accurate for the Cautious group (68%) than for the Confident (82%), Depressed (91%) and Unmotivated (84%) groups.

2 Design phase

Thanks to the user research phase, a first model was designed proposing an initial organization of the content and functionalities envisaged. To validate these proposals, we adopted a participatory design approach with healthcare professionals and patients. First, we held a workshop with healthcare professionals to present them with the first wireframe. Then, we set up a focus group of 5 patients and 5 individual interviews to collect the opinions of the future users. Overall, the results showed that the application meets the main expectations of the participants. Potential users are confident in their ability to use the application, and frequent or even daily use is envisaged.

In the end, 4 main modules make up the application:

- Physical activity: The objective is to accompany the user in planning and practicing physical activity through pre-designed and personalized exercise programs. The exercises are displayed in video format so that the user can perform the movements at the same time as the virtual coach.
- Pain management: This module aims to offer tools for self-management of pain through 2 functionalities: (1) meditation exercises in audio format and (2) textual advice in case of pain.
- Daily: This module is divided into two categories: Ergonomics and Knowledge. The Ergonomics module aims to provide advice on postures for everyday activities. In line with the concept of therapeutic education, the Knowledge category offers four quizzes to deconstruct false beliefs and increase user motivation: (1) Understanding my low back pain, (2) The benefits of physical activity, (3) Preconceived ideas and (4) Understanding my pain.
- Tracking: The aim is to track the user's performance according to their frequency of physical activity, their pain level and their mood.

One of the challenges of mobile intervention is to offer a service and content adapted to each user. To do this, our user model is based on 2 criteria: the level of physical activity (beginner, intermediate or expert) and the motivational profile (Unmotivated, Cautious, Depressed or Confident). Depending on the level of physical activity, we propose 3 adapted physical activity sessions. The motivational profile allows us to recommend certain contents and functionalities and to present adapted motivational messages (Figure 2).

In order to guide the user to the content and functionalities adapted to their profile, we use a dynamic button called "My priority" on the home interface to redirect to the recommended modules. Once the user has accessed the content in question, the button disappears to make way for the next priority. Based on the characteristics of

each of the profiles studied, different priorities can be proposed or not, depending on their needs. Thus, the Unmotivated is characterized by the highest amotivation. According to the HAPA model, the motivational phase corresponds to the reinforcement of the individual's attitude in order to bring him/her to the intention of changing his/her behavior. Therapeutic education (TVE) [50] aims to meet this objective by enabling the acquisition of improved knowledge about the disease. Thus, we suggest that the "Understanding my low back pain" quiz be used first for this Unmotivated profile. In addition, like the Cautious profile, the Unmotivated presents fears and beliefs about physical activity, which is why the quizzes "The benefits of physical activity" and "Received ideas" are recommended next. Regarding the depressive symptoms of our Unmotivated, Cautious and Depressed profiles, several factors can explain this phenomenon, starting with the presence of pain. Some CBT techniques aim at decentering the pain through education and information, learning coping strategies and reassurance, stress management, relaxation, mindfulness meditation, hypnosis, etc. [51]. Their effectiveness is documented in the literature and they are the subject of numerous international recommendations for improving physical and psychological well-being [52]. The "Understanding my pain" quiz is therefore based on the therapeutic education recommended in pain management in order to understand the underlying mechanisms and the difference between pain and suffering. Following this, we recommend the Pain Management module as a priority, which includes management tips and meditation audios. According to the HAPA model, the second phase (volitional) requires a passage through an action and adaptation plan. Therefore, we propose to use planning through the "Plan my activity" priority for each of the profiles. The Confident profile is characterized by the highest self-efficacy and mental health. In accordance with the HAPA model, we consider that this profile is already in the volitional phase, which is why we direct it to the planning of sessions.

The construction of motivational messages to promote physical activity has been the subject of numerous studies, allowing Williamson et al [53] to make certain recommendations. The first is that messages should be formulated in a positive way, with a particular emphasis on the benefits of physical activity on social and mental health in order to increase motivation and the feeling of self-efficacy. A second recommendation is that messages should be brief and avoid threat-based language. For clinical populations, messages should be delivered by health professionals to maximize acceptance. With this in mind, we designed the messages to firstly reinforce patients' sense of self-efficacy and then motivation. For the messages to reinforce the feeling of self-efficacy, we based ourselves on the average scores of the profiles for each of the 10 items of the FC-CPSES. We consider an item to have a low score if the average of the cluster is below 6, which is the average of the total score of our sample (maximum score: 10). Based on these results, we constructed a similar message for the Unmotivated, Cautious and Depressed profiles with the aim of increasing their self-efficacy to control/manage depression and breathlessness. Another message exclusively for the Depressed is aimed at increasing their self-efficacy in managing their symptoms and obtaining information about their illness. For the Unmotivated and Cautious profiles, two additional messages were constructed to increase their self-efficacy in managing their symptoms, doing chores and exercising regularly. Since the Depressed and Confident profiles already have a high level of intrinsic motivation, we assume that they are in the volitional phase of the HAPA model. In this phase it is recommended to strengthen the maintenance and recovery self-efficacy for physical activity. That is why we have constructed an additional message for them in this sense.

For the motivational messages specific to physical activity, we used the EMAPS and EMI-2 items [54] to construct 31 messages: 8 to reinforce intrinsic motivation, 7 to reinforce integrated regulation, 10 to reinforce identified regulation and 6 to reinforce introjected regulation. For the adaptation of the messages, we based ourselves on the results of the EMAPS profiles. The Unmotivated and the Cautious show low scores for all types of motivation. Based on the principle that the different regulations are situated on a continuum of self-determination [23], we propose to present them with messages to reinforce introjected regulation, then identified, then integrated and finally intrinsic motivation. For the Depressed and Confident profiles, they support a strong sensitivity to identified, integrated regulation and intrinsic motivation with a certain predominance for identified

regulation. Following the logic of the self-determination continuum, we have chosen messages for them to reinforce identified, integrated regulation and intrinsic motivation.

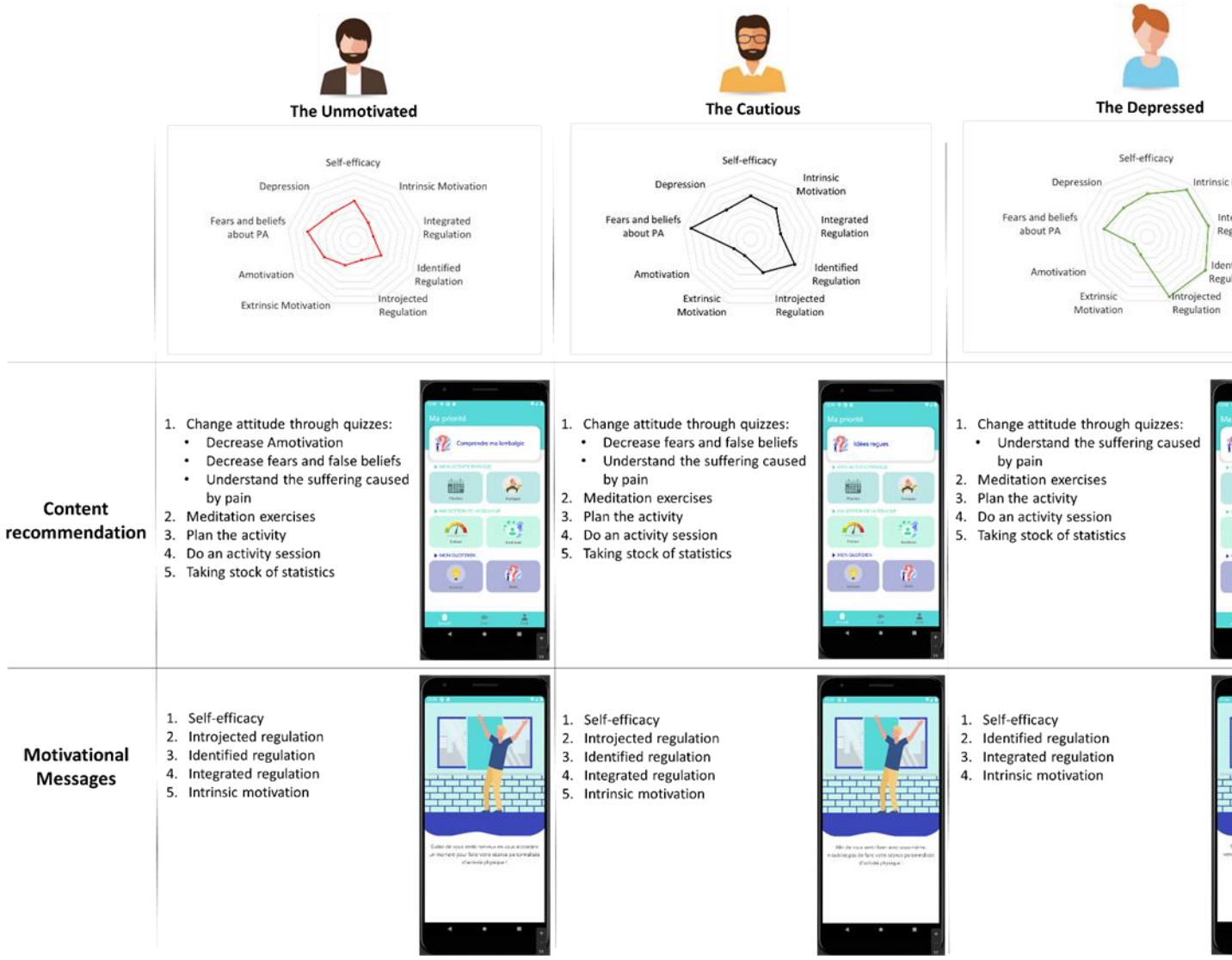

Figure 2: Tailoring of the system according to the motivational profile

3 Conclusion

This work describes an original method combining theories in psychology of motivation and behavior change with a user-centered approach to design a personalized mobile application for low back pain patients.

A first version of this application was designed through a participatory design with doctors and patients. It aims at a global support for a change of attitude and behavior towards pain and physical activity. Unlike the

majority of available applications, it was designed by drawing on the computer science and psychology literature to design a digital intervention promoting health behavior.

On the other hand, we were able to define users' needs and expectations and build profiles based on psychological characteristics to adapt the system. Regarding this adaptation, we chose to make recommendations of functionalities to accompany the process of behavioral change of users as well as messages to reinforce their self-efficacy and motivation.

At this stage, the aesthetics and ergonomics of the application have been evaluated via several iterative tests with the general public, patients and various project partners. A first experiment is currently underway to test the impact of the proposed tailoring according to the identified profiles, and the first results suggest that participants do perceive the adapted version as more personalized and resulting in a better user experience. The protocol has been accepted by an Ethics Committee. As a result of this study, a second version will be proposed and tested in a randomized controlled trial.

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