The WhiteTeeth app

The development and evaluation of a smartphone app for promoting oral health behavior and oral hygiene in adolescent orthodontic patients

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General introduction
Fixed orthodontic treatment
Orthodontics is the branch of dentistry concerned with facial growth and the development of the dentition, and with occlusion and the prevention and correction of occlusal anomalies [1]. Approximately 53-57% of Dutch 12-year olds undergo orthodontic treatment—some 100,000 patients each year [2]. Most of these patients are treated using fixed orthodontic appliances (orthodontic brackets), which are used to correct a wide range of dental and skeletal malocclusions and to align teeth. These appliances are fixed to the teeth, forces being applied by the archwires or auxiliaries attached to them [1]. Such is usually performed during adolescence, when the eruption of permanent teeth is complete but craniofacial growth is still progressing. This combines advantages in terms of tooth movement, correction of malocclusion and the maintenance of favorable facial growth [3].

The main objectives of orthodontic treatment are to achieve pleasant smile aesthetics with a stable occlusal relationship and healthy masticatory function [1]. The improvements brought by orthodontics to a patient’s facial and dental appearance can also have mental health benefits, as they increased the patient’s psychosocial well-being and sense of self-esteem and self-confidence [1,4]. As the ideal alignment of the teeth simplifies oral hygiene, it is also supposed to reduce dental caries and periodontal diseases.

White spot lesions
Individuals with malocclusions typically have many retention sites to which oral bacteria can adhere. The irregularities of the teeth make it easier for dental plaque or a biofilm to form. Bonding attachments such as fixed orthodontic appliances to the teeth also create retention sites on surfaces that are not generally susceptible to caries. As these appliances make it difficult to clean the regions surrounding the bracket, they hamper the maintenance of oral hygiene, explaining why biofilm-related complications such as periodontal inflammation and dental caries formation are common during fixed orthodontic therapy [5-7].
General introduction

CHAPTER 1

Fig. 1. Opaque white spot lesions or decalcification around the brackets and along the gingival margins (picture by courtesy of P.R. Kolodziej).

Fig. 2. Cavities developed during orthodontic treatment with fixed appliances (picture by courtesy of P.R. Kolodziej).

The severity of dental caries can range from decalcification (i.e., white spot lesions; Fig. 1), through the loss of the surface integrity of the enamel, to cavitation (Fig. 2) [8]. White spot lesions can develop rapidly in the four weeks between one orthodontic appointment and the next [9]; nearly 25% patients with fixed orthodontic appliances have clinically visible enamel demineralization [10]. Demineralized tooth enamel can absorb stains from food and beverages, which eventually discolor the white spot lesions into brown spots [11]. After the removal of orthodontic appliances, these lesions can remain visible for life, their opacity or discoloration seriously compromising aesthetics, potentially canceling out the beneficial aesthetic effect of the orthodontic treatment [11].

Oral health recommendations and adherence in orthodontics

As the prolonged accumulation of dental plaque is an important factor in the development of oral diseases, the maintenance of good oral hygiene is essential to prevent oral conditions such as white spot lesions. The use of fluoride agents is another effective way of preventing the development and progression of decalcification and lesions. Orthodontic healthcare providers therefore recommend their patients to brush their teeth at least twice daily and to use additional dental aids, such as a proxy brush or dental floss, for effective plaque plaque removal, as well as to use fluoridated toothpaste (1450 ppm fluoride) and mouth rinse (0.05% NaF). They also recommend the consumption of an appropriate diet that avoids foods that can debond fixed appliances or increase the risk of dental caries [12].

To prevent white spot lesions during fixed orthodontic treatment, it is essential that patients adhere to such oral health recommendations. Adherence is defined as the extent to which a person’s behavior—such as following a diet—is consistent with the recommendations they have agreed with healthcare provider [13]. If orthodontic patients do not adhere to these recommendations, treatment outcomes may be compromised; in some instances, it may be necessary to terminate treatment prematurely. Due to poor oral hygiene, it is estimated that the appliances of 5%-10% of orthodontic patients are removed to prevent further decalcification before orthodontic treatment has been completed [14].

Low adherence to oral health recommendations and poor maintenance of oral hygiene are considerable problems in adolescent orthodontic patients [15, 16]. For example, Geiger et al. showed that fewer than 15% of orthodontic patients rinsed daily with fluoride as requested [17]. Similarly, Aljabaa et al. showed that over 50% of orthodontic patients reported never flossing [18].

Oral health promotion programs in orthodontics

Several programs have been designed to promote oral health among adolescent orthodontic patients. In 2014, Aljabaa et al. conducted a systematic literature review on the effectiveness of these programs. They found the following four randomized controlled trials, each of which used different methods to improve oral hygiene in orthodontic adolescent patients [18]:
Due to the use of modern technology—such as mobile devices—the delivery of oral health promotion programs is evolving [24]. The provision of health promotion programs via mobile devices is known as mobile health (mHealth). As the implementation of such programs may contribute to oral health promotion in patients who receive orthodontic treatment, the WhiteTeeth app was developed. The WhiteTeeth app is an mHealth program intended to promote better oral health behavior and oral hygiene among adolescents with fixed orthodontic appliances. The aim of this dissertation is to describe its development, content and evaluation.

After a general description of mHealth, the following paragraphs describe the effectiveness of current mHealth programs in orthodontic adolescent patients and how they can be optimized.

**Mobile health (mHealth)**

MHealth has emerged as a sub-segment of electronic health (eHealth), which involves the use of information and communication technology (ICT) for health services and information [25]. MHealth was first introduced and defined in 2003 as mobile-computing, medical-sensor and communications technologies for healthcare [26]. A definition used at the 2010 mHealth Summit of the Foundation for the National Institutes of Health (FNIH) was “the delivery of healthcare services via mobile communication devices” [27]. Today, the term mHealth refers to “the practice of medicine and public health supported by mobile devices”. Most commonly, it refers to the use of mobile communication devices (such as mobile phones or smartphones, tablets and personal digital assistants) and wearable devices (such as smart-watches), for health services, information and/or data collection” [26].

In the past ten years, mobile phones have rapidly evolved into handheld computers—i.e., smartphones. The introduction of smartphones has played a major role in the evolution of mobile health. While the functions of older-generation mobile phone comprised voice communication and text messages (i.e., Short Messages Service (SMS)), the technology available in smartphones has extended functionality.

**Text messaging in orthodontics**

As text messaging works both on the simplest mobile phones and on the more advanced smartphones, it provides a unique opportunity to send patients cues or information on their phones [28]. A recent systematic review with meta-analysis of randomized controlled trials showed that adolescent orthodontic patients who received text messages reminders had better oral hygiene with less plaque accumulation and gingival bleeding over time than those who did not receive such messages [29]. It also showed that the development of white spot lesions was reduced when a weekly text message explaining the importance of oral hygiene or containing reminders of oral health recommendations was sent to adolescent orthodontic patients or their
parents [29]. Text-message reminders sent to orthodontic patients also helped to reduce patients’ self-reported pain and failure to attend appointments [30-32].

Text messaging is a simple intervention to develop and use; not only are its content and schedule customizable, it also provides a push-mode delivery that prompts users to read. On the other hand, it offers limited interaction. As a result, its engagement is merely passive. Neither does it use the latest smartphone features. Using modern smartphone technology may therefore lead to further optimization and greater changes in oral health behavior and outcomes [28].

**Smartphones**

New generation smartphones have a powerful computing capacity, a very large memory, various hardware devices (such as cameras, GPS, and sensors), links to various networks (such as 4G and Wi-Fi) and open operation systems that encourage software application development. The release of the iPhone in 2007 led the way for developers to create a library of software applications (apps) available to users. Apps are software programs that have been developed to run on a mobile device in order to accomplish a specific purpose. Users can browse a library (such as Google Play or Apple App Store), search for specific apps that serve their needs, and then download them onto their mobile device.

Smartphones have gained popularity as a personal communication device; using them for communication is now part of people’s lifestyle. In 2017, there were over 2.3 billion smartphone users worldwide, and forecasts suggest that 2.8 billion of the world’s population will use a smartphone by 2020 [33]. The high use and various features of smartphones make them suitable for the delivery of health promotion programs [34]. As portable devices tend to be switched on and to remain with the owner throughout the day, they provide opportunities for bringing behavioral programs into important real-life contexts involving people's decisions about their health and the barriers they encounter to behavior change [34, 35]. Similarly, the connectedness of smartphones facilitates the sharing of behavioral and health data with other people, such as parents, peers and as healthcare providers [34,35]. Due to their ability to provide a wealth of information quickly and efficiently, smartphones are also a valuable information source. And due to their increasing ability to use sensors to infer context such as user location and movement, there is now a prospect of continuous and automated tracking of health-related behaviors and timely, tailored programs for specific contexts [34].

The medical community has embraced smartphone technology, making a great number of health-related apps available for patients and healthcare providers [36,37]. As early as 2012, an estimate put the number of health-related apps at no fewer than 40,000 [28]. Many commercial apps have already been developed to help people manage stress, improve mood, follow a healthy diet, manage weight, increase physical activity, quit smoking, and self-manage chronic health problems [38,39]. From basic apps composed of text-message reminders to sophisticated apps that coordinate the management of chronic diseases or coach behavioral change, apps have a multitude of functions in health and healthcare [28]. But despite the evidence showing that apps can be a useful adjunct to traditional healthcare, various areas and gaps in our knowledge remain to be explored—including the use of apps as an intervention tool for oral health promotion in orthodontics [39].

**Orthodontic apps**

In 2017 there were at least 354 apps on orthodontics across Android and Apple operating systems [40]. Most of them have very simple functions and do little more than provide basic information, and provide information on malocclusion, remind patients about elastic wear, track treatment progress, and promote orthodontic products. Very few focus on oral health promotion [40-42].

Despite the high number of orthodontic apps now available, only two apps for oral health promotion have been evaluated for their effectiveness [39,43,44]. Zotti et al. 2015 evaluated a WhatsApp-based program that consisted of instructions to download video tutorials on maintaining oral hygiene during orthodontic treatment, and using a chat room called the “Brush Game” [43]. Patients in this chat room were allowed to share information, pictures and movies on oral hygiene and orthodontic treatment. To show their oral hygiene status in this chat room, they were also asked to share two self-photographs (“selfies”) weekly, before and after using a plaque-disclosing tablet. Every week, a moderator published a ranking of the five best participants. After 6, 9, and 12 months, this app was shown to provide an effective way of improving oral hygiene and oral health in adolescents with fixed appliances.

In another study, Alkadhi et al. designed a mobile app to improve oral hygiene among adolescents with fixed orthodontic appliances [44]. It consisted of videos of oral hygiene instructions and text messages encouraging patients to practice oral hygiene three times a day. Patients allocated to the app and those in the control group received traditional oral health education in an orthodontic clinic. After 4 weeks, the study showed that the app had improved oral hygiene levels effectively.

Although text messages and these orthodontic apps improved oral hygiene effectively in adolescent orthodontic patients, patients’ oral hygiene was still not optimal (i.e., dental plaque levels were still high) after the intervention period, and most of the follow-up periods were short-term. Neither was much detail provided on program content—a problem for future researchers, who thus have few options for replicating effective programs or for attempting to design programs that are more effective. There is therefore a need for optimized oral health promotion programs and high-quality studies evaluating them.
CHAPTER 1

Optimizing oral health promotion programs

The objective of oral health promotion is to induce behavior change and to reinforce and maintain healthy behavior that will contribute to good oral health [45, 46]. Traditionally, on the principle that improving patients’ knowledge of their disease may lead them to adopt good oral health behaviors, many oral health promotion programs have focused on the provision of oral health knowledge and instructions [46]. However, research has shown that oral health knowledge and instructions alone are not enough to establish long-term behavior change [47]. Instead, behavior can successfully be changed and maintained by influencing its determinants [48]. Behavioral determinants are causal factors of a particular behavior. As the desired behavior can be induced and maintained by influencing its behavioral determinants, programs should be designed to influence the important determinants related to the particular behavior.

Researchers have developed and tested models or theories of health behavior that identify behavioral determinants and specify the pathways whereby the determinants influence behavior. In other fields of dentistry it has been shown that oral hygiene, oral health behaviors and their determinants are improved more effectively by oral health promotion programs that were designed on the basis of a behavioral theory—and thus targeted behavioral determinants—than by programs that were not based on theory [47,49]. On the basis of reviews of orthodontic programs promoting oral health, whether face-to-face or via a mobile device [23,40,41,43], it can be concluded that most program developers did not use behavioral theories in their program design, but based their programs on common sense. Neither do most programs contain behavior change techniques. Such techniques—also known as behavior change methods—are general techniques or processes that have shown an ability to change one or more determinants of behavior and have their origins in behavioral and social science theory [48]. The application of relevant behavioral theories and evidence can inform the selection of behavior change methods, thereby increasing a program’s potential effectiveness [50].

Programs incorporating more behavior change methods tended to have greater effects on behavior than those incorporating fewer methods—possibly a consequence of the fact that different methods target different aspects of the behavior change process [50]. In addition, because studies of orthodontic programs did not describe the determinants targeted by the program or did not evaluate their effect on behavioral determinants, the mechanisms underlying change in oral health behavior in orthodontics are still not understood. For this reason, future studies should not only design theory-based programs targeting the behavioral determinants, but also describe and evaluate their effects on these determinants.

Theories of health behavior change and maintenance

Recent theoretical work on health behavior change, and especially maintaining health behaviors, has focused on self-regulation processes, which can be defined as those “mental and behavioral processes by which people enact their self-conceptions, revise their behavior, or alter the environment so as to bring about outcomes in line with their self-perceptions and personal goals” [51]. Self-regulation involves the setting of goals, cognitive preparations, and the ongoing monitoring and evaluating of goal-directed behavior [52]. Even though different theories emphasize different aspects of self-regulation processes, there is an overlap in the constructs underlying most of these theories. Two phases are commonly distinguished: motivational and volitional. Most earlier theories have focused on the motivational phase of the self-regulation process—a phase that ends with a decision on the goal to be pursued (i.e., intentions) [52]. These theories are known as motivational theories.

Motivational theories assume that the determinant that is most proximal and most important to the performance of a particular behavior is the intention (or motivation) to engage in that behavior. Examples of such motivational theories are the Theory of Reasoned Action (TRA; later extended and changed into the Theory of Planned Behavior) and the Attitude-Social influence-self-Efficacy (ASE) model [53-55]. According to these motivational models, intentions are determined by three factors. The first is attitude, which is based on beliefs or outcome expectancies and is the overall (positive or negative) evaluation of a behavior or behavioral goal. The second factor is social influence, which is based on injunctive or descriptive norms and is defined as what other important people think or do with regard to the behavior or behavioral goal. The third factor is perceived behavioral control or self-efficacy [53], i.e., an individual’s perception of his or her ability to perform a specific behavior. A positive intention towards behavior is expected to result from a positive attitude, positive social influences, and a high self-efficacy regarding the performance of the behavior.

Overall, according to these motivational theories, any increase in intention regarding the respective behavior will lead to a concomitant increase in behavioral engagement [56,57]. However, Sheeran et al. (2002) have shown that intentions to adopt new behaviors do not always lead to actual behavior change [58]. In other words, intention alone is not enough to explain behavior—there is a gap between intention and behavior, the so-called “intention-behavior gap” [58]. As motivational theories do not address the question of translating intentions into action, they have been much criticized [59]. Research has increasingly sought to address this question by developing models of the role of cognitive factors in the post-intentional phase, i.e., the volitional phase. One such model is the Health Action Process Approach (HAPA) model [60], which holds that changing health behaviors involves two interacting phases: the motivational (pre-intentional) phase and volitional (post-intentional) phase.
The motivational phase corresponds largely to the theoretical framework of most motivational models. According to HAPA, the motivation (i.e., intention) to adopt health behavior is underlain by the combination of three factors: a growing risk perception, plus outcome expectancies, plus action self-efficacy. Before people start considering the benefits and disbenefits of possible actions (i.e., outcome expectancies) and think about their competence to actually perform them (i.e., action self-efficacy), they should feel personally susceptible to risks, and should understand the risk-behavior relationship (i.e., risk perception). Once intentions have been formed, the volitional phase starts. The behavioral intention has to be transformed into specific planning of when, where, and how to perform the desired action (i.e., action planning), and planning of anticipated barriers and ways to overcome them (i.e., coping planning). Planning is strongly influenced by self-efficacy, as self-efficacious individuals achieve mastery through earlier planning, and visualize successful scenarios that may guide their goal-attainment (i.e., maintenance or coping self-efficacy). People who are confident in their ability to cope with setbacks (i.e., have recovery self-efficacy) will recover quickly if they run into unforeseen difficulties. Once the behavior has been initiated, people may benefit from self-regulatory cognitions that help them to control and maintain the behavior (i.e., action control).

In other fields of medicine, behavior has been changed successfully by programs based on theories involving the pre-intentional/motivational and post-intentional/volitional phases, HAPA being one such theory [60]. In dentistry, however, most of the theories used to explain oral health behavior have addressed only the motivational determinants that lead to behavioral initiation. Theories that include motivational and volitional determinants may thus help to explain and identify important determinants of oral health behavior. If these determinants were targeted, oral health promotion programs could then be optimized, as they would target not only the initiation of behavior, but also its maintenance.

**Theories on behavior change techniques or methods**

As well as theories that can explain the behavior change process and factors that may influence it, there is a series of health behavior change theories that explain how change can be achieved by using behavior change methods to change the behavior change mechanisms (i.e., determinants). One example is Social Cognitive Theory (SCT) [61]. The determinants of behavior described by SCT include outcome expectancies, self-efficacy, and the perceived behavior of others. According to SCT, perceived behavior of others is not only a determinant of behavior, but also a very effective method for behavior change through modeling. Modeling is the principle of observing another person’s behavior, of experiencing reinforcement by observing a person (i.e., a model), and of learning on the basis of this observation how this behavior is performed. An important feature of behavior change theories is that they explain when such methods are likely to be effective. For instance, modeling is likely to be effective when the model is a role model rather than a mastery model, when it can be identified with, and when the person observing also has the skills necessary to performing the behavior [48].

Considerable gains have been made in identifying theory-based methods that can change and maintain health behaviors effectively (e.g., Michie et al., [2009]; Dusseldorp et al. (2014); Webb et al. (2010) [48, 50, 57, 62-64]). Taxonomies have been developed that explain core methods, define relevant constructs, and present the preconditions for the methods to be effective (for examples of taxonomies of health behavior change methods; see Kok et al. (2015) and Michie et al. (2011) [62 63]). The theoretical background for methods in these taxonomies is provided in Bartholomew et al. (2016) [48]). These taxonomies can be used to inform the selection of behavior change methods.

**Tailoring content and meeting the needs of the target-group**

As shown by studies on a range of health behaviors [65], the efficacy of health promotion messages can be influenced by the tailoring method. Tailoring is defined as “any combination of information or change strategies intended to reach one specific person, based on characteristics that are unique to that person, are related to the outcome of interest, and have been derived from individual assessment” [66]. When tailoring an mHealth program, an application on a mobile device is programmed to generate personalized feedback. As personalized feedback in the form of messages can be provided only on the basis of a particular input from a recipient, individuals answer questions on their health, behavior and (presumed) behavioral determinants. The answers are entered into the mobile device, which is connected through the app to a database [66]. The data are linked to a library that contains health education messages that are suited to a range of possible answers. Software with an if-then algorithm is used to link the answers to the messages. Per individual, the program then generates feedback. Although tailoring can increase the potential effectiveness of oral health programs, none of the available orthodontic apps have used tailored messages.

If a program is to fit the needs of the target group, it is essential not only to understand the needs of the target group, but also to involve the target group in the process of developing the program. To date, only one study has reported that the target group was involved in the design of an orthodontic app [67]. Without the information provided by needs analysis and target group, there is little hope of designing an oral health promotion program that the target group will understand and adopt [48].
How to optimize programs: a brief summary of findings and of studies evaluating these programs

In conclusion, orthodontic programs promoting oral health should not only be based on behavioral theories, but should also incorporate behavior change methods that target various determinants—such as the motivational and volitional factors—that are important in a behavior change process. To optimize oral health promotion programs, program developers should consider incorporating a wide variety of behavior change methods in their program. They should also consider incorporating behavior change methods that have shown to be effective in changing health behavior but have not yet been incorporated in existing orthodontic programs. For example, tailoring can increase the potential effectiveness of oral health programs. To allow replication of the program, researchers need to provide enough details on the content of their programs. To ensure that the program will be accepted and adopted, they should also investigate the needs of the target group. Studies of these programs should describe the behavioral determinants targeted by the intervention, and subsequently evaluate each program’s effect on these determinants.

Using intervention mapping

It can still be a challenge to select theories, translate them into behavior change methods, and then translate them into a program design for actually modifying behavior successfully. The selection and translation processes may be helped by intervention mapping (IM), which provides technical assistance with identifying theory-based determinants and matching them with appropriate methods for change [48]. A protocol for the planning and systematic development of health promotion programs, IM has been used successfully in the development and evaluation of various evidence-based health promotion programs [48].

The IM process comprises six steps: (Step 1) Conducting a problem analysis that identifies what needs to be changed and for whom (i.e., identifying target behaviors and behavioral determinants); (Step 2) Specifying program outcomes and objectives; (Step 3) Selecting behavior change methods that match the determinants and objectives, and translating these methods into practical strategies (i.e., program components) that satisfy the criteria for the effectiveness of the methods selected; (Step 4) Producing a fully structured program; (Step 5) Planning for the adoption and implementation of the program; (Step 6) Generating an evaluation plan [48].

Each of these steps comprises several tasks, in each of which theory and evidence are integrated. The completion of the tasks per step creates a product that guides the subsequent step. The completion of all of the steps serves as a blueprint for designing, implementing and evaluating an intervention on the basis of a foundation of theoretical, empirical and practical information. By using intervention mapping to develop and to plan the evaluation of a smartphone app for preventing white spot lesions through the promotion of oral health behavior and oral hygiene, this dissertation project aimed to contribute to the current lack of evidence in this field of dentistry.

Hypothesis and outline of this dissertation

The hypothesis was that the app would be effective in improving oral hygiene, oral health behavior and the psychosocial factors of oral health behavior. Mapping the development and content of the app is useful because it allows researchers to replicate effective programs, or make attempts to design programs that are even more effective [68].

Understanding oral health behavior makes it possible to identify targets for programs designed to promote good oral health behavior. For this reason, a systematic literature review and cross-sectional study were conducted. Chapter 2 presents the systematic literature review with meta-analysis on the psychosocial correlates of oral hygiene behavior, which aimed to identify the psychosocial factors of oral hygiene behavior among adolescents. Chapter 3 presents the results of a cross-sectional study, which was conducted to test whether the findings of the meta-analysis could be generalized to the specific target group: adolescents with fixed orthodontic appliances. After the identification of important factors influencing the oral health behavior of adolescent orthodontic patients (i.e., the intervention targets), the WhiteTeeth app was developed systematically by following the steps of the intervention mapping protocol. Chapter 4 describes the results of applying the first five steps of intervention mapping. To help define program objectives, part of this systematic process involved semi-structured interviews. To achieve these objectives, the app integrates behavioral strategies that target the underlying factors of behavior identified in the first step of intervention mapping. Chapter 5 presents the study protocol for the effect evaluation of the app—the sixth step of intervention mapping. Chapter 6 consists of a randomized controlled trial in which the app was compared with standard treatment for its effect on outcomes such as oral health behavior, plaque control, gingival bleeding and the psychosocial factors of oral health behavior. Finally, chapter 7 summarizes the main findings of this dissertation.
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CHAPTER 1


