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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A mobile app (WhiteTeeth) to promote good oral health behavior among Dutch adolescents with fixed orthodontic appliances: Intervention Mapping approach.
The WhiteTeeth app: Intervention Mapping approach

ABSTRACT

Background: The insertion of fixed orthodontic appliances increases the risk of dental caries, particularly in adolescents. Caries can be prevented through good oral health behavior. To support adolescents with fixed orthodontic appliances and for promoting oral health behavior, we developed a theory- and evidence based mHealth program, the WhiteTeeth application (app).

Objective: The objective of our paper was to describe the systematic development and content of the WhiteTeeth app.

Methods: For systematic development of the program, we used the Intervention Mapping (IM) approach. In this paper, we present the results of applying the first 5 steps of IM to the design of an mHealth program: (1) identifying target behaviors and determinants through problem analysis, including (I) a literature search, (II) a survey study, and (III) semi-structured interviews to explore adolescent oral health behavior during orthodontic therapy; (2) defining program outcomes and objectives; (3) selecting theoretical methods and translating them into practical strategies for the program design; (4) producing the program, including a pilot test with 28 adolescents testing the acceptability and usability of the WhiteTeeth app; and (5) planning implementation and adoption.

Results: On the basis of our literature search, we identified fluoride use and control of dental plaque levels (e.g. tooth brushing and proxy brush usage) as target behaviors for preventing caries. Next, we identified important and changeable determinants of oral health behavior that fitted the theoretical concepts of the Health Action Process Approach (HAPA) theory. The HAPA theory, the self-regulation theory, and the results of the semi-structured interviews were used to define the program objectives, that is, the performance and change objectives. After defining the objectives, we identified multiple behavior change techniques that could be used to achieve these objectives, such as providing of oral health information and feedback, prompting self-monitoring, coaching of set action and coping plans, and sending reminders. We translated these methods into practical strategies, such as videos and a brushing timer. Next, we combined these strategies into a single program resulting in the WhiteTeeth app (which is available on both iTunes and Google Play stores as "Witgebit"). Adolescents with fixed orthodontic appliances and dental professionals were included in the development process to increase the success of implementation. The pilot test revealed that the app users appreciated and liked the app. The WhiteTeeth app can be integrated into current orthodontic care.

Conclusion: IM allowed us to identify multiple techniques that have been shown to be the most effective in initiating behavior change, but have not yet been incorporated into existing orthodontic apps. The WhiteTeeth app contains all these techniques,
CHAPTER 4

The WhiteTeeth app: Intervention Mapping approach

INTRODUCTION

Dental caries remains a major public health problem that affects young people and adults [1]. Worldwide, nearly 60%-90% of young people and the majority of adults have dental caries, which often leads to pain and discomfort [2-4]. In several industrialized countries, oral diseases are the fourth most expensive disease to treat [2]. Furthermore, 5%-10% of public health expenditure is devoted to oral health treatment [5-6].

Adolescents with fixed orthodontic appliances are at high risk of developing dental caries [7], as their fixed orthodontic appliances (e.g. brackets) impede oral hygiene procedures and restrict salivary and mucosal self-cleaning capacity, unfavorably altering the balance of oral bacteria and increasing the retention of dental plaque. [8-10]. Prolonged dental plaque accumulation can lead to enamel demineralization, which is an early stage of dental caries. Due to their white appearance, these demineralizations are often referred to as white spot lesions, which are a common complication in orthodontics [11]. The incidence of patients who develop at least one new white spot lesion during orthodontic treatment ranges from 68% to 95% [12-14]. White spot lesions may develop around the bracket, their white appearance seriously compromising aesthetics [15,16]. After the removal of fixed orthodontic appliances, white spot lesions often remain permanently visible; along with being unaesthetic, they increase the risk of lesion progression [15,16].

Oral health education is essential for the prevention of dental caries in patients with fixed orthodontic appliances. A central role in such education – which is given both before and during orthodontic treatment [17] – involves oral health behavior that target dental plaque control, dietary behavior and fluoride administration [18-21]. However, it is not always easy to achieve regularity in patient compliance with such oral health behaviors [22]. A recent study among Dutch adolescents with fixed orthodontic appliances showed that they had poor overall oral hygiene and poor compliance with the use of fluoride mouth rinse [23]. This emphasizes the need for interventions that focus on changing in oral health behavior in this group.

As growing numbers of young people now have smartphones, mobile phone apps may be effective means of promoting oral health behavior in orthodontics [24-26]. As a delivery method, apps have many advantages: they are constantly accessible, can be adjusted to the needs of the user, can provide tailored feedback, are more anonymous than face-to-face contact, can send cues to action (i.e. reminders), and have a wide reach and interactive features, such as animations [27-29].

To promote good oral health behavior among adolescents with fixed orthodontic appliances, we decided to develop a smartphone app, the WhiteTeeth app (Dutch name: WitGebit app). To ensure that this app would be both theory- and evidence-based and also be feasible for use in orthodontic clinics, we used the IM protocol [30] for its systematic development. This paper provides a detailed description of the development and content of the WhiteTeeth app.

METHODS

Intervention Mapping Protocol
IM is a protocol for the planning and development of theory- and evidence-based health promotion programs [30]. The IM process comprises six steps: Step 1, identifying target behaviors and determinants through problem analysis; Step 2, specifying program outcomes and objectives; Step 3, selecting theoretical methods and practical strategies for the program design; Step 4, producing the program; Step 5, planning the implementation and adoption; and Step 6, planning for evaluation [30]. Each step has a defined end product and consists of various tasks that are required for the systematic integration of theoretical and empirical information. The product of a preceding task or tasks guides the developmental activities for the subsequent step or steps.

To guide the developmental process for this intervention, we established a multidisciplinary planning group consisting of an orthodontist, a dental hygienist, two dentists, a smartphone application developer, a health psychologist, two health scientists, and a child psychologist with communication expertise.

Step 1: Problem analysis
The first step of the IM process was to conduct a problem analysis, which included the identification of determinants related to the problem and the specific health-related behaviors. This IM process is based on the assumption that health outcomes can be improved by targeting health behavior and their determinants [30]. To explore the oral health behaviors of adolescents during treatment with fixed appliances, we conducted semi-structured interviews with adolescents with such appliances (n=20), asking them about their oral health behavior. These semi-structured interviews were performed after a regular orthodontic check-up in a private room at the Academic Centre for Dentistry Amsterdam (ACTA). Adolescents with fixed orthodontic appliances were...
purposively sampled to ensure that the patient group ranged in gender, educational level, ethnicity and dental hygiene level. The clinicians told adolescents about the aim of the study and the voluntary nature of participation. Their parents or legal representative were given written information about the study. Informed consent was obtained from both the adolescents and their parents. During the interview, we asked adolescents about their beliefs and motivations concerning the performance of oral health behavior during fixed orthodontic treatment. Interview topics relevant to the adolescents’ oral health behaviors consisted of: (1) oral hygiene practices; (2) reasons or motives for performing oral health behaviors; (3) awareness and knowledge of dental health and recommendations on oral health (see Table 1); and (4) personal strategies and reported barriers; (4) role of the social environment; (5) facilities (accessibility). The adolescents were individually interviewed using open-ended questions to guide the interview. The audiotaped interviews were anonymously transcribed verbatim and transported to a software program “NVivo” to analyze the transcripts. After 20 interviews saturation was attained, i.e. no new relevant information emerged in subsequent interviews. The Medical Ethics Committee of the University of Amsterdam approved this qualitative study (VUMC - 2014-577).

After exploring adolescent oral health behavior during orthodontic treatment through these semi-structured interviews, we searched the literature to identify behavioral determinants and theoretical constructs to explain this behavior. We therefore conducted a systematic literature review with a meta-analysis [33]. Since the findings of this review applied to young people in general, not specifically those with fixed orthodontic appliances, we conducted a survey among adolescents undergoing fixed orthodontic therapy (n=116) [23]. This survey study aimed to explain oral health behavior and the presence of dental plaque during orthodontic treatment. A sample of 116 adolescents (12-15 years) with fixed orthodontic appliances was recruited from an orthodontic clinic situated in Almere (the Netherlands) and the respondents completed a questionnaire to map their oral health behavior. In addition, a dental hygienist measured their dental plaque levels. Linear regression analyses were performed to examine the factors associated with dental plaque and specific oral health behaviors [23].

Next, the planning group selected important and changeable determinants of oral health behaviors. According to IM, the importance of determinants is related to the strength of the relationship between the determinants and oral health behavior. The changeability of the determinants that can be achieved by an intervention and the importance of the determinants were established by the development group on the basis of the available scientific literature [23, 30, 33-40] and consensus judgments.

### Table 1. Oral health recommendations for patients with fixed orthodontic appliances from the Academic Centre for Dentistry Amsterdam, (ACTA).

<table>
<thead>
<tr>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- To control dental plaque levels, it is recommended to brush the teeth at least twice a day according to the “5-step method” and to use dental aids (such as a proxy brush to clean the tooth surfaces around the brackets and/or to maintain gingival health). The “5-step method” consists of brushing (1) the gums; (2) above and (3) under the bracket on the buccal surfaces of the teeth; (4) the chewing surfaces and (5) the lingual or palatal sites of the teeth. This 5-step procedure takes approximately three minutes to fulfill [31].</td>
</tr>
<tr>
<td>- Daily use of fluoride mouth rinse and toothpaste during orthodontic treatment is strongly advised for the prevention of dental caries [20, 31].</td>
</tr>
<tr>
<td>- The consumption of sugars, refined carbohydrates and or, dus acid or soft drinks should be limited [32].</td>
</tr>
</tbody>
</table>

### Step 2: Identification of program outcomes and objectives

Step 2 involved a detailed specification of program outcomes and objectives indicating those behaviors that needed to change to achieve the overall goal of the program, i.e. to prevent dental caries in adolescents during orthodontic treatment and to prevent existing dental caries from getting worse. The performance objectives formalized the behavioral changes that adolescents with fixed orthodontic appliances needed to make to achieve the behavioral goals of the program (the program outcomes). Per program outcome, two researchers (JS and PvE) defined performance objectives on the basis of the following question: “To perform the desired behavior, what, in concrete terms, do participants in this program need to do?” Next, the same two researchers identified specific determinants that would be deemed useful in changing each performance objective. For example, if a performance objective was “to decide to prevent dental diseases and to change their tooth brushing behavior”, appropriate behavioral determinants may be “risk perception”, “knowledge”, “outcome expectancies” and “self-efficacy”. Subsequently, we formulated change objectives that stated what needs to change in determinants to achieve the performance objectives. The change objectives were the result of combining performance objectives with the changeable determinants of oral health behavior. Thus, to give an example, the determinant was adolescents’ “self-efficacy”, and the performance objective was “adolescents decide to prevent dental diseases and to change their tooth brushing behavior”. In this example, the change objective would be for “adolescents with fixed orthodontic appliances to feel able to prevent dental diseases and to gain confidence in their ability to brush their teeth twice daily according to the 5-step method”. The first author constructed a matrix (as explained by IM [30]) specifying performance objectives, behavioral determinants and change objectives, which were subsequently validated by the planning group.
Step 3: Program design: Selecting theoretical methods and practical strategies for program design

The third step of IM comprised two phases. In the first phase, we identified and selected theoretical methods. Theoretical methods or behavior change techniques are considered general techniques or processes that have been shown to enable change in one or more behavioral determinants, and which have their origins in behavioral and social sciences theories. One example of a theoretical method is modeling, which is frequently used to facilitate behavior change [30]. For each behavioral determinant and in conjunction with the change objective, two researchers (JS and PvE) selected theoretical methods on the basis of the literature on existing dental and orthodontic health promotion interventions [36-52] and behavior change techniques [30, 53, 54]. For example, to reach the change objective “adolescents monitor their tooth brushing behavior and dental plaque levels”, we selected the methods “self-monitoring of behavior” and “self-monitoring of the outcome of behavior” for changing the determinant “action control”.

In the second phase, we assessed the conditions under which the methods are shown to be effective and 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” [30]. For example, the selected method “self-monitoring of behavior” was translated into the practical strategy “adolescents enter into the app whether or not they accomplish their daily oral health tasks”. The planning group decided if the methods and strategies were suitable for the target population and appropriate for designing a smartphone app. When necessary, small changes were made, resulting in strategies that were easier to implement.

Step 4: Program production

In the fourth step, we combined the chosen strategies into a coherent program leading to the development of the WhiteTeeth app. First, the strategies were clustered to create a program plan, which described the intervention components and presented the wireframe drafts. To ensure that the program met the users’ needs and expectations, we organized meetings with the target audience to obtain feedback on the program plan. Helen Parkhurst, a high school in Almere, the Netherlands, allowed us to organize two meetings with 30 adolescents (most had current or previous orthodontic appliances) attending preuniversity technology classes. The first author showed the wireframe drafts and offered a brief demonstration of the main functionalities of the app. As an assignment for a technology class, adolescents were asked to give feedback on the program plan and to design an app. During the second meeting, adolescents presented their app design. New ideas or suggestions for improvements to optimize the program plan were discussed with the planning group. Based on the adjusted version of the program plan, the first author created an adapted version of the app wireframes to increase to increase the app’s acceptability and usability. These adapted wireframes were then improved by a user experience designer. The WhiteTeeth app was developed by ACTA in collaboration with Inholland University of Applied Sciences and TNO Research group. A programmer at ACTA programmed the WhiteTeeth app using Ionic software (ionicframework.com), which enabled the app to function on two operating systems: IOS ≥7 and Android ≥4.1.

To identify aspects of the program that could be improved, the WhiteTeeth app 1.0 was pilot tested. It was first tested for bugs (i.e. system errors) by the planning group (resulting in WhiteTeeth 1.1). Second, to increase the app’s acceptability and usability, it was pilot-tested for two weeks by 28 adolescents with fixed orthodontic appliances, who then provided feedback on its acceptability and usability in an online survey containing 49 questions. The survey measured perceived usefulness, attractiveness and ease of use, and included the System Usability Scale (SUS) for measuring the app’s usability [55]. The SUS scale ranged from 0 to 100, with response ranges from strongly agree to strongly disagree. A SUS score above 68 would be considered above average. This questionnaire has been published elsewhere [56]. The results of the pilot test were used to refine the WhiteTeeth app (resulting in WhiteTeeth 1.2).

Step 5: Program implementation plan

The previous steps of IM were focused on ensuring the effectiveness of the program. The purpose of the penultimate step of IM is to ensure that the program reaches the intended population by preparing for the adoption and implementation of the program [30]. The planning began by identifying who would use the program; who would adopt it, who would implement it, and who would be responsible for sustaining the program over time. The best way to increase the chances for successful implementation is collaborating with future program implementers from the start of the planning process, thereby linking program developers with program implementers. Dental health professionals were therefore involved throughout the entire process. The planning group discussed the adoption and implementation of the app.

Step 6: Evaluation plan

In the final step of IM, an evaluation plan was created. As this final IM step for is not within the scope of this paper, it is reported in detail elsewhere [56].
RESULTS

Step 1: Problem analysis
Semi-structured interviews with adolescents with fixed orthodontic appliances provided insight into their oral health behavior. These interviews revealed that recommended dental aids, such as proxy brushes, were used only occasionally. Although most respondents stated that they brushed their teeth twice a day as a matter of routine, they often failed to brush for as long as recommended. These respondents had little awareness of the benefit of fluoride and fluoride mouth rinses were not a preventive measure they chose consciously. The dietary recommendations were familiar to most respondents, but many of them did not fully adhere to these recommendations. The main reasons for performing desired or undesired oral health behaviors are listed in Table 2. Respondents shared the opinion that their parents (especially mothers) were helpful with dental care, since they influenced the availability of dental aids and supported the adolescents by reminding them to clean their teeth.

The relevant literature was systematically reviewed to identify those behavioral determinants and theoretical constructs that best explained adolescent oral health behavior. The results of this systematic literature review with meta-analysis revealed that the psychosocial factors most strongly correlated with oral health behavior were “self-efficacy”, “intention”, “social influences”, “coping planning” and “action planning”. These factors that are part of the Health Action Process Approach (HAPA) theory [33]. The findings of this review applied to the oral health behaviors of young people in general.

Our survey study (n=116) revealed that the HAPA theory could be applied to explain the differences in oral health behaviors in adolescents with fixed orthodontic appliances [23]. According to this theory, behaviors are established in two subsequent phases: (1) a motivational, intention-forming phase, and (2) a volitional phase in which intention is translated into action [57]. Regarding the motivational phase, the motivation (i.e. intention) to adopt health behavior is formed by a growing “risk perception”, “outcome expectancies”, and “action self-efficacy”. A minimum level of threat must exist (“risk perception”) before people start considering the benefits of possible actions (“outcome expectancies”) and think about their competence to actually perform these (“action self-efficacy”) [57]. Once intentions are 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 (“action planning”) and planning of anticipated barriers and ways to overcome them (“coping planning”). Planning is strongly influenced by self-efficacy because self-efficacious individuals achieve mastery through planning, and they visualize successful scenarios that may guide goal attainment (“maintenance or coping self-efficacy”). Persons with confidence in their ability to cope with setbacks will quickly recover when running into unforeseen difficulties (“recovery self-efficacy”). When the behavior has been initiated, self-regulatory cognitions to control and maintain the behavior must be activated (“action control”) [57].

Next, the planning group selected important and changeable determinants of oral health behaviors, which are presented in Table 3.

Step 2: Identification of program outcomes and objectives
The results of the problem analysis were used to specify the program outcomes, performance objectives and change objectives, which are described below.

The program outcomes were specified as follows:
(1) Adolescents control their dental plaque levels by improving:
   (a) their tooth brushing frequency and duration, that is, by brushing their teeth consistently and correctly (6-step method, see Table 1) at least twice daily; and
   (b) cleaning around the brackets with a dental aid (e.g., a proxy brush).
(2) Adolescents increase their exposure to fluoride (i.e., a fluoride mouth rinse).
## Table 3. Our selection of significant determinants of oral health behaviors

<table>
<thead>
<tr>
<th>Determinants</th>
<th>Importance</th>
<th>Changeability</th>
<th>Evidence for importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge and awareness</td>
<td>+</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>Risk perception</td>
<td>+</td>
<td>+</td>
<td>r = 0.20, p &lt; 0.001</td>
</tr>
<tr>
<td>Attitude and expectancies</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Subjective norm</td>
<td>++</td>
<td>+</td>
<td>r = 0.26, p &lt; 0.001</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>+++</td>
<td>+</td>
<td>r = 0.37, p &lt; 0.001</td>
</tr>
<tr>
<td>Intention</td>
<td>+++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Planning (action and coping)</td>
<td>+++</td>
<td>+</td>
<td>r = 0.52, p &lt; 0.001</td>
</tr>
<tr>
<td>Self-regulatory skills, such as action control</td>
<td>+++</td>
<td>+</td>
<td>Maintaining behavior</td>
</tr>
<tr>
<td>and goal commitment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor skills</td>
<td>++</td>
<td>+</td>
<td>Precondition for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>improvement in self-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>efficacy</td>
</tr>
<tr>
<td>Habit</td>
<td>+++</td>
<td>+</td>
<td>Making a certain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>behavior automatic</td>
</tr>
<tr>
<td>External:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social influences:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Parental behavior</td>
<td>+++</td>
<td>+</td>
<td>r = 0.41, p &lt; 0.001</td>
</tr>
<tr>
<td>- Dental professional</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Cues</td>
<td>+++</td>
<td>+</td>
<td>Most direct environ-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mental influence</td>
</tr>
<tr>
<td>Access /Availability</td>
<td>+++</td>
<td>+</td>
<td>Making healthy behavior</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>easier</td>
</tr>
</tbody>
</table>

Note: Importance = the strength of the evidence for the relationship between the determinant and oral health behavior we want to change; changeability = the strength of the evidence that the proposed change can be realized by a program; + = not very important, not easy to change; ++ = important, changeable; +++ = very important or easy to change. Correlation and significant levels are based on results from previous studies on oral health and behavior change [23, 30, 33-40].

## Table 4. Seven performance objectives (PO1-PO7) and 23 change objectives (CO1-CO23) pertaining to program outcome 1a “Adolescents control their dental plaque levels by improving tooth-brushing”.

<table>
<thead>
<tr>
<th>Performance objective (PO)</th>
<th>Determinant</th>
<th>Change objective (CO)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PO1:</strong> Adolescents decide to prevent dental diseases and to change their tooth brushing behavior.</td>
<td>Risk perception</td>
<td>CO1: Are aware of their susceptibility to dental diseases</td>
</tr>
<tr>
<td><strong>PO2:</strong> Adolescents choose or plan how to improve their tooth brushing behavior</td>
<td>Goal-commitment, Self-efficacy</td>
<td>CO9: Choose a change about which they feel self-efficacious</td>
</tr>
<tr>
<td><strong>PO3:</strong> Adolescents prepare strategies to establish how they will change their tooth-brushing behavior.</td>
<td>Action planning</td>
<td>CO11: Plan in terms of when and where to brush their teeth</td>
</tr>
<tr>
<td><strong>PO4:</strong> Adolescents change their tooth brushing behavior.</td>
<td>Support</td>
<td>CO13: Receive support during brushing on when and for how long to brush teeth</td>
</tr>
<tr>
<td><strong>PO5:</strong> Adolescents evaluate their tooth brushing behavior, their dental plaque levels, and the effect of brushing on these levels.</td>
<td>Self-regulatory skills – action control</td>
<td>CO15: Monitor their tooth brushing behavior and dental plaque levels</td>
</tr>
<tr>
<td><strong>PO6:</strong> If adolescents have difficulty attaining their tooth-brushing/dental plaque goal, adolescents identify possible solutions.</td>
<td>Self-regulatory skills, Awareness</td>
<td>CO16-C017: Examine how well their performance corresponds to agreed goals, and consider modifying goals accordingly</td>
</tr>
<tr>
<td><strong>PO7:</strong> Adolescents maintain the desired tooth brushing behavior.</td>
<td>Coping-planning, Action control</td>
<td>CO18: Identify and anticipate barriers and ways to overcome them</td>
</tr>
<tr>
<td><strong>PO8:</strong> Adolescents have difficulty maintaining their desired tooth brushing behavior.</td>
<td>Self-efficacy</td>
<td>CO19: Gain confidence to deal with possible barriers</td>
</tr>
<tr>
<td><strong>PO9:</strong> Adolescents engage in social influences to maintain their desired tooth brushing behavior.</td>
<td>Social influences</td>
<td>CO20: Enlist others to help overcome barriers</td>
</tr>
<tr>
<td><strong>PO10:</strong> Adolescents feel positive about tooth brushing.</td>
<td>Expectancies</td>
<td>CO22: Feel positive about tooth brushing</td>
</tr>
<tr>
<td><strong>PO11:</strong> Adolescents believe that long-term benefits can be achieved by maintaining tooth brushing over time</td>
<td>Expectancies</td>
<td>CO23: Believe that long-term benefits can be achieved by maintaining tooth brushing over time</td>
</tr>
</tbody>
</table>
The next stage was to stipulate the performance and change objectives for each of the specific program outcomes. The results of the semi-structured interviews (see step 1), in combination with the frameworks of the HAPA[57] and self-regulatory theory [58] were used to define the performance objectives. Self-regulation theory provides an understanding of the behavioral processes needed for adequate self-management in order to obtain a behavioral goal. As such, it is very useful to define subsets of behaviors. Once the performance objectives had been specified, we created a matrix of change objectives by linking performance objectives to behavioral determinants. In order to design the program, 21 performance objectives and 69 accompanying change objectives were defined. Due to the similarities between the performance objectives for all program outcomes, a selection is presented in Table 4. Table 4 presents 7 performance objectives (PO1-PO7) and 23 change objectives (CO1-CO23) pertaining to program outcome 1a (“Adolescents control their dental plaque levels by improving tooth brushing”).

Step 3: Program design: selection of theoretical methods and practical strategies

After careful consideration of parameters for use, theoretical methods and practical strategies addressing the determinants were selected to achieve the change objectives. The determinants and change objectives, their linked theoretical methods and practical strategies for program outcome 1 “adolescents control their dental plaque levels by improving their tooth brushing frequency and duration” are presented in Table S1 (see Appendix A).

The following paragraphs present the selected theoretical methods and their translation into practical strategies for the same seven performance objectives (POs) (Step 2).

PO1 – Providing health risk information, personal advice and instructions

Suitable methods for supporting decision-making on oral health behavior include providing health risk information on oral health behavior, and giving personal advice and instructions (targeting determinants: “risk perception”, “outcome expectancies”, and “knowledge”) [53]. To personalize dental advice and instructions, the app collects information on adolescents’ oral health behavior and dental plaque levels. Adolescents were asked to answer questions covering their tooth brushing frequency, their use of fluoride mouth rinse and dental cleaning aids, the duration of their brushing sessions, and the type of toothbrush they used. Next, they were asked to use disclosing tablets in order to visualize their dental plaque. The app then showed an example of a selfie, asked them to take a selfie of the teeth where plaque was visualized, and also asked them to indicate the plaque by clicking on the selfie (the app is installed in the orthodontic clinic, where a dental hygienist provided instructions on using the disclosing tablets and using the smartphone to take a selfie of the teeth). Based on the number of clicks (i.e. the amount of plaque) and answers to the questions, the app provided personal advice on oral health behavior (see Table 5 for the algorithm). If an adolescent did not adequately control his or her plaque levels or if his or her oral health behavior was poor, health risk information was offered via a short animated movie, which depicted the likely development of white spot lesions. This, and an image of beautiful white teeth, were shown as outcomes resulting from complying with oral health recommendations – and thus provided adolescents with two motivation for performing the desired oral health behavior.

Our semi-structured interviews showed that doubts about personal oral hygiene skills and the perceived complexity of the techniques were important barriers to the use of dental cleaning aids. To target adolescents’ self-efficacy, movies of a peer model were shown (adolescent with fixed orthodontic appliances), demonstrating how to clean teeth correctly (according the 5-step method - see Table 1) that have fixed orthodontic appliances (Fig. 1). This demonstration was tailored to the kinds of toothbrushes the adolescents used.
Table 5. The algorithm of personal recommendations that were provided based on the plaque assessment and answers to the registration questions.

<table>
<thead>
<tr>
<th>Flow</th>
<th>Answer options (the answer)</th>
<th>Interpretation of the answers and personal recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Question A: Tooth brushing frequency &lt;2 times/day (0/1), OR</td>
<td>The user does not follow the tooth brushing recommendations and/or dental plaque is present.</td>
</tr>
<tr>
<td></td>
<td>Question B: Tooth brushing frequency &lt;3 min/day (0/1), OR</td>
<td>The app provides information on health risk plus recommendations and instructions. It helps to set goals for increasing brushing frequency and duration. It advises users to use the brushing timer and to monitor their tooth brushing frequency daily.</td>
</tr>
<tr>
<td></td>
<td>Dental plaque is visible on the selfie.</td>
<td>The user follows the proxy brush recommendations and dental plaque is not present. Continue to question C – flow 2</td>
</tr>
<tr>
<td>1.2</td>
<td>Question A: Tooth brushing frequency &gt;2 times/day (2/3 or more often), AND</td>
<td>The user follows the proxy brush recommendations and dental plaque is absent or present.</td>
</tr>
<tr>
<td></td>
<td>Question B: Tooth brushing duration ≥3 min/day (3/4 min or longer), AND</td>
<td>The user follows the tooth brushing recommendations and/or dental plaque is present.</td>
</tr>
<tr>
<td></td>
<td>Dental plaque is or is not visible on the selfie.</td>
<td>The user follows the proxy brush recommendations, but dental plaque is present. Continue as flow 2.1</td>
</tr>
<tr>
<td>2.1</td>
<td>Question C: Proxy brush usage &lt;1 time/day (0), AND</td>
<td>The user does not follow the proxy brush recommendations and/or dental plaque is present.</td>
</tr>
<tr>
<td></td>
<td>Dental plaque is or is not visible on the selfie.</td>
<td>The app provides information on health risk plus recommendations and instructions. It helps to set goals for increasing the use of a proxy brush and for increasing tooth brushing frequency and duration. It advises users to use the brushing timer and to monitor their tooth brushing frequency and proxy brush usage.</td>
</tr>
<tr>
<td>2.2</td>
<td>Question C: Proxy brush usage 1 time/day (1/2 or more often), AND</td>
<td>The user follows the proxy brush recommendations, but dental plaque is present.</td>
</tr>
<tr>
<td></td>
<td>Dental plaque is visible on the selfie.</td>
<td>The user follows the proxy brush recommendations and dental plaque is absent. Continue to question D – flow 3</td>
</tr>
<tr>
<td>2.3</td>
<td>Question C: Proxy brush usage 1 time/day (1/2 or more often), AND</td>
<td>The user follows the proxy brush recommendations and dental plaque is absent. Continue to question D – flow 3</td>
</tr>
<tr>
<td></td>
<td>Dental plaque is not visible on the selfie.</td>
<td>The user follows the proxy brush recommendations and dental plaque is present. The app provides information on health risk plus recommendations and instructions. It helps to set goals for increasing the use of fluoride mouth rinse. It advises users to monitor their fluoride mouth rinse usage.</td>
</tr>
<tr>
<td>3.1</td>
<td>The user does not have 3 fluoride moments per day:</td>
<td>The user does not follow the fluoride recommendations.</td>
</tr>
<tr>
<td></td>
<td>Question A: Tooth brushing frequency &lt;3 times/day (0/1/2), OR</td>
<td>The app provides information on health risk plus recommendations and instructions. It helps to set goals for increasing the use of fluoride mouth rinse. It advises users to monitor their fluoride mouth rinse usage.</td>
</tr>
<tr>
<td></td>
<td>Question D: Fluoride mouth rinse usage &lt;1 time/day.</td>
<td>The user follows all recommendations. Positive reinforcement.</td>
</tr>
<tr>
<td>3.2</td>
<td>The user has 3 fluoride moments per day:</td>
<td>The user follows all recommendations.</td>
</tr>
<tr>
<td></td>
<td>Question A: Tooth brushing frequency ≥3 times/day (3 or more often), OR</td>
<td>The user follows the tooth brushing recommendations and/or dental plaque is present.</td>
</tr>
<tr>
<td></td>
<td>Question D: Daily fluoride mouth rinse usage.</td>
<td>The user follows the fluoride recommendations and/or dental plaque is present.</td>
</tr>
</tbody>
</table>

PO2 – Goal setting
Goal setting can help adolescents to choose how to improve their oral health behavior (targeting the determinant: "skills") [34]. Important conditions for the success of goal setting are the adolescent’s commitment to the goal and the fact that the goals are challenging, but lie within the adolescent’s abilities to achieve them. To ensure their commitment, adolescents chose a health behavior goal that best matched their preferences and abilities. In a series of questions, the app guided them through the process of defining one or more oral health goals. The adolescents then selected an oral health behavior he or she would like to change, for example, improving the frequency and duration of tooth brushing and the use of a proxy brush or a fluoridated mouth rinse. The answers were presented as clear goals on the main page of the app.

PO3 – Planning and behavioral contracting
Planning (i.e., formulating action plans) and contracting were identified as methods for preparing oral health behavior change (targeting determinants: "action planning" and "attitude") [37-39, 44-46]. The app asked questions, which guided the adolescents in the creation of action plans by specifying goals in terms of when and where they should act. The answers were presented as their action plan, which would state where and when they would brush their teeth. This action plan was formulated as an implementation intention (“If situation X arises, then I’ll do Y”). When one or more goal were formulated, the adolescent agreed to the overall action plan by signing a contract in the app. This was saved on its main page. The action plan was linked to the option for setting reminders.

PO4 – Practical support (The Brushing timer)
To establish oral health behavior change, practical support was identified as a useful method [53]. To provide practical support, the app incorporated a brushing timer, which users could turn on when they decided to brush (targeting determinants: “support”). The timer showed how much time had elapsed. Throughout brushing, it also supported good brushing, according to the 5-step method, by showing where to brush (location in the mouth). Figure 2 shows a screenshot of the brushing timer. When brushing with the brushing timer was completed, the app congratulated the user on fulfilling the task.

PO4 – Prompt cues (Reminders)
Since numerous studies have shown that sending short message service (SMS) text messages as prompt cues is an effective way for establishing behavior changes and improving oral hygiene during fixed orthodontic treatment [48-50], the app also provided an option for setting reminders for oral health behavior tasks (including monitoring of behavior and dental plaque) and the use of the brushing timer (targeting determinants: "cues to action or habit formation"). The reminders were sent as push notifications.
PO5 – Prompt self-monitoring
We identified prompt self-monitoring as a suitable method for evaluating tooth brushing behavior and dental plaque levels (targeting determinants: “self-regulatory skills or action control” and “awareness”) [36, 40, 51, 52, 59]. The use of disclosing agents provided a suitable method of monitoring plaque levels and thereby improved oral hygiene [59]. When the app was installed in the orthodontic clinic, a dental hygienist explained how oral health behavior and plaque levels should be monitored. The next day, the app sent a push notification that urged the adolescents to monitor their oral health behavior daily by entering into the app whether they accomplished their daily dental activities. If they failed to complete the monitoring, a push notification was sent the next day. Each week, adolescents were asked via the app to evaluate their dental plaque levels and review their behavioral goals. For this purpose, they were asked to use a disclosing tablet to visualize the dental plaque, to take a selfie of the result and to indicate the visualized dental plaque. On the basis of the information on the selfie and the activities performed that week, the app concluded whether the adolescent’s goals had attained. It then congratulated the adolescent for using the app, and, if necessary guided him or her in setting goals or adapting existing ones, and in creating coping plans.

PO6 – Prompt barrier identification to establish coping plans (Volitional sheets)
We identified prompt barrier identification and the creation of coping plans as suitable methods for helping adolescents to identify possible ways of achieving their oral health goal if they encountered difficulties (targeting determinants: “self-regulatory skills or action control”, “coping self-efficacy” and “coping planning”) [40, 60, 61]. If adolescents failed to attain their goals, coping plans could be formulated [57]. These plans use “if-then” formulations to specify how they would deal with difficult situations. However, although adults realized positive effects for if-then planning (i.e., implementation intentions [60-61] on oral health behavior were undertaken with adults [40], it is possible that planning interventions would be less suitable for adolescents, who may be less familiar with creating behavioral coping plans. To mitigate this, the app therefore incorporated volitional help sheets [62] – a tool for constructing effective (if-then) coping plans – by asking participants to link difficult situations (where “if” indicates barriers against performing the desirable behavior) with a behavioral response (where “then” indicates solutions) [47]. For example, “If I often forget to brush my teeth, then I ask someone at home to remind me to brush my teeth.” Table 6 shows the content of a volitional help sheet intended to establish coping plans for tooth brushing behavior. The content of the volitional help sheets was informed by the results of the semi-structured interviews (performed in step 1). To remind the adolescents of their coping plans, the plans were saved on the main page of the app, and thus were visible when the app was opened.

PO7 – Providing positive reinforcement (Coaching text messages)
Maintaining oral health behavior requires long-term commitment. Providing reinforcement by sending coaching SMS text messages was identified as a suitable method of motivating adolescents to maintain the desired behavior (targeting determinants: “attitude” and “maintenance self-efficacy”) [53]. To personalize coaching SMS text messages, adolescents were asked what outcomes motivated them to maintain good oral health. They could select from pre-established motives such as “keeping my gums healthy,” “getting fresh breath,” or “white teeth.” If desired, these notifications could be switched off.
CHAPTER 4

Step 4: Program production

The practical strategies were clustered into 4 main program components: (1) Registration to help adolescents to decide to change their oral health behavior, to choose how to change it, and to plan appropriate actions; (2) behavior change to help adolescents to actually change their behavior with respect to their daily oral health routines; (3) evaluation to help adolescents to evaluate their behavior change over the past week and to adapt goals weekly and; (4) maintenance to help adolescents to maintain their behavior. Table 7 shows an overview of the flow of the program.

Table 6. An example of the content of the volitional help sheet used to establish coping plans for tooth brushing behavior.

<table>
<thead>
<tr>
<th>Difficult situations</th>
<th>Possible solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(If) I am too tired to brush my teeth</td>
<td>Then I think of the dentist who has to fill all the cavities</td>
</tr>
<tr>
<td>(If) I don’t feel like tooth-brushing</td>
<td>Then I think of the brown spots and cavities I might get if I don’t brush my teeth</td>
</tr>
<tr>
<td>(If) I want to skip tooth brushing because I’m in a hurry</td>
<td>Then I think about how fresh and clean my teeth will feel after brushing</td>
</tr>
<tr>
<td>(If) I want to skip tooth brushing because I’ve got something much more fun to do</td>
<td>Then I ask someone at home to remind me to brush my teeth</td>
</tr>
<tr>
<td>(If) I’m so busy that I don’t have time for tooth-brushing</td>
<td>Then I think about the bad breath I can get if I don’t brush my teeth</td>
</tr>
<tr>
<td>(If) I prefer not to brush my teeth because they’re sensitive or painful</td>
<td>Then I set a reminder</td>
</tr>
<tr>
<td>(If) I don’t want to brush my teeth because it’s too difficult</td>
<td>Then I think of tooth brushing giving me fresh breath and white teeth</td>
</tr>
<tr>
<td>(If) I prefer not to brush my teeth because my gums are bleeding</td>
<td>Then I look in the mirror and say to myself: “I can do it! Every day!”</td>
</tr>
<tr>
<td>(If) I’m too tired to brush my teeth in the evening</td>
<td>Then I watch the movie about tooth brushing in the app</td>
</tr>
<tr>
<td>(If) I ………….. (option to fill in)</td>
<td>Then ………….. (option to fill in)</td>
</tr>
</tbody>
</table>

Table 7. An overview of the flow of the WhiteTeeth app: targeted performance objectives.

1. Registration – First day (PO1-PO3)
   - Users are required to respond to registration questions and provide some personal information.
   - The app asks users to visualize dental plaque using disclosing tablets and to indicate the plaque, on the selfie.
   - On the basis of the information collected on their oral health behavior and dental plaque the app then provides health risk information, personal advice and instructions in short videos.
   - Next, it helps the users to customize their personal oral health goals, creating action plans and setting reminders.
   - At the end of installation, it encourages them to use the brushing timer and monitor their oral health behavior every day.

2. Behavior change - Every day (PO4)
   - When they decide to brush, they have the option of turning on the timer. Afterwards, the app provides positive reinforcement.
   - Users receive a push notification on a daily basis to monitor their behavior.

3. Evaluation - Every week (PO5, PO6)
   - Users are asked by the app to evaluate their dental plaque levels, to review their behavioral goals, and to create coping plans if needed.

4. Maintenance – Every 3 days (PO7)
   - Users receive coaching SMS text messages.

The final program: the WhiteTeeth app

The app was listed on both iTunes and Google Play stores as the “WitGebit” app. The WhiteTeeth (“WitGebit”) app was made available free of charge for IOS ≥7 and Android ≥4.1 operating systems.

Pilot test of the WhiteTeeth app

The most important finding of the pilot test was that adolescents with fixed orthodontic appliances liked and appreciated the WhiteTeeth app, particularly the movies with instructions on how to use of proxy brushes. The mean SUS score was 77, indicating an acceptable score for usability. Since the app users suggested changing the amount of storage of the WhiteTeeth app, we compressed the movies to reduce the storage of the app to 52.8MB. The app users also suggested improving the instructions for the brushing timer and the statistics for evaluating their behavior. Even though the users requested to include gamification, this could not be included due to financial limitations. The program was adapted using their feedback.
Step 5: Program implementation plan
The planning group agreed to deliver the intervention through dental professionals that already had regular contact with adolescents receiving orthodontic therapies, thereby allowing the app to be implemented within existing oral health care processes. One of the barriers to implementation perceived by the dental professionals was the limited time they had during appointments. They therefore recommended that we created an app that could operate as a stand-alone program. To encourage adolescents to use the WhiteTeeth app, several practical strategies were planned. For example, if the adolescents did not use the app for 3 days, the app used the registration information to send personalized SMS text messages reminding them to use the app, such as “Brushing your teeth will help to keep them healthy and beautiful.”

DISCUSSION

This paper describes the development process and content of the WhiteTeeth app. The WhiteTeeth app was developed to promote oral health behavior among adolescents with fixed orthodontic appliances who were at high risk of developing dental caries. We used an IM protocol as a tool for the systematic development of the app [30]. IM linked the phases of intervention development to theory and empirical evidence and made the process of program development transparent. IM was proven to be a suitable method for developing health promotion programs for various health issues [63-65]. In the field of orthodontics, authors did not describe the process of program development explicitly in their publications [41, 42, 48-50, 66-70]. This limited opportunities for comparison. Mapping the development and contents of an intervention, as in this study, is useful because it allows researchers to faithfully replicate effective programs, or make attempts to design programs that are even more effective [71]. In contrast to other studies, our study used theory to inform the program design. The use of theory was necessary to ensure that the factors related to achieving change were addressed [72, 30]. When reviewing the few available orthodontic apps promoting oral health, we concluded that the integration of behavior change techniques was limited in these apps [25, 69, 70, 73, 74]. However, a meta-analysis revealed that programs with a larger differentiation of behavior change techniques tended to have larger effects on behavior than programs that incorporated fewer techniques, which may be a consequence of the fact that different techniques target different aspects of the behavior change process [72]. In addition to this matter, behavior change techniques were the most effective for initiating behavior change, such as creating action and coping plans, [72, 75] were not incorporated into these apps. Our app contains multiple proven techniques that focus on the motivation and initiation of oral health behavior changes. We believe this makes it a unique and promising mHealth program for oral health promotion.

Our work represents a major contribution to the field of oral health care, as it is the first study to systematically develop an mHealth program based on sound evidence and theory. The involvement of dental professionals and adolescents enabled us to develop a feasible program which offered ample opportunities for effective implementation in the future. To increase the likelihood that the app would meet the preferences of the target group, we invited a user experience designer to participate in the app development and also included future users through semi-structured interviews and a pilot test. Interaction with the adolescents enabled us to create program materials, such as volitional sheets that listed barriers and solutions, suited to the individual situations of the target members. Our problem analysis helped us to identify important determinants that were not addressed by the existing oral health programs, such as volitional factors that are outlined in the HAPA theory [57]. Using the IM protocol ensured that all important app objectives were addressed in the WhiteTeeth program, based on the theoretical insights and methods, empirical findings and practical strategies.

However, there were some limitations that should be highlighted. Despite the value of this robust development process, IM is very time-consuming. Our experience in this regard was similar to that of other researchers who used the IM protocol [76-80]. Our development process required more time than expected because we had to carry out additional research to gain insights into oral health behaviors and its determinants during orthodontic treatment (step 1), as there was little information available on these topics.

Another challenge regarding IM, as others have acknowledged [78-81], was the complexity of detailing the performance and change objectives. Program developers and researchers recognized that targeting multiple complex behaviors may create a high degree of complexity since data obtained during the development process can become cumbersome and overwhelming [79, 81]. In our study, the creation of matrices of change objectives was particularly time-consuming and resulted in an overwhelming amount of information about what should be targeted by the program. During our development process we excluded an important target behavior, intake of sugar-sweetened beverages, in order to manage the data of our study and the complexity of our program [82].

The use of IM enabled us to create the WhiteTeeth app, a unique and promising mHealth intervention for Dutch adolescents with fixed orthodontic appliances. This app incorporated several behavior change techniques, such as self-monitoring, goal setting and volitional sheets. The app simultaneously targeted important
determinants of oral health behavior change. The lessons learned from using the IM process have relevance for researchers and practitioners, especially considering the current paucity of evidence-based oral health promotion programs for orthodontic patients and their failure to incorporate important behavior change techniques addressing meaningful behavioral determinants. Our future randomized controlled trial will indicate whether the app is effective in improving adolescent oral health.

Conflicts of interest
None declared.

ACKNOWLEDGMENTS

We would like to thank A. Laan for programming the app, J. van Schendel (user experience designer) for improving its design; H. Ullerup (user experience designer) and N. Scheerman (psychologist with communication expertise) for their expertise regarding the intervention’s design and delivery and participating the planning group; C. Hoek for helping with analysis of the qualitative data; A. Springer for helping to test the app; M. van der Veen for helping organizing meetings with the adolescents; We would also like to thank the planners, especially G. Kramer, G. Verrups, M. van den Braak, for participating in planning group; and D. Alexander and D. Visser for their careful reading of the manuscript.

ABBREVIATIONS

ACTA: Academic Centre for Dentistry Amsterdam
App: mobile phone application
CO: Change Objective
HAPA: Health Action Process Approach
IM: Intervention Mapping
mHealth: mobile health
PO: Performance Objective
RCT: Randomized Controlled Trial
SUS: System Usability Scale

Appendix 1: [Performance objectives, selected change objectives, theoretical methods and practical strategies for program outcome 1 “adolescents control their dental plaque levels by improving their tooth brushing frequency and duration”.]

REFERENCES

CHAPTER 4


42. Aljabaa A, McDonald F, Newton JT. A Randomized Controlled Trial to Compare 3 Methods Designed to Enhance Adherence among Orthodontic Patients. JDR Clinical & Translational Research 2016 Feb;1(1):59-68. DOI:10.1177/2380084416267130


### Table S1. Performance objectives, selected change objectives, theoretical methods and practical strategies for program outcome 1 "adolescents control their dental plaque levels by improving their tooth brushing frequency and duration".

#### PO1 Adolescents decide to prevent dental diseases and to change their tooth brushing behavior.

<table>
<thead>
<tr>
<th>Change objectives (determinant)</th>
<th>Theoretical methods/ BCTs</th>
<th>Requirements</th>
<th>Practical strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents are aware of their susceptibility to dental diseases (risk perception).</td>
<td>- Providing feedback on behavior (BCT 2.2): i.e., monitoring and providing informative or evaluative feedback on performance of behavior [34, 35].</td>
<td>Adolescents need to possess some sub-skills (they need to know how to use the disclosing tablets and take a selfie).</td>
<td>In the orthodontic clinic (upon installing the app), a dental hygienist demonstrates how to use the disclosing tablets to visualize plaque and how to take a selfie.</td>
</tr>
<tr>
<td>Adolescents are able to describe their tooth brushing behavior (awareness).</td>
<td>- Using disclosing tablets to visualize and evaluate dental plaque [33]. - Providing feedback on outcome (BCT 2.7): i.e., monitoring and providing feedback on the outcome of the behavior[34, 35].</td>
<td>Feedback needs to be personal and specific.</td>
<td>To provide feedback, information on adolescents’ oral health behavior and dental plaque levels will be collected. Adolescents will first be asked to answer questions with regard to their oral health behavior. Next, adolescents are asked to use disclosing tablets to visualize the dental plaque. After they use the tablets, they are asked to take a selfie of their teeth with the visualized plaque (red color). The app presents an example of a selfie and the selfie will be stored on the main page of the app. The app asks them to click the number of clicks and registration questions, the app provides feedback on their dental plaque levels and oral health behavior, and provides oral health advice.</td>
</tr>
<tr>
<td>Adolescents know what good oral health is and its association with dental plaque (knowledge). Adolescents acknowledge the risk of not brushing teeth as recommended and its consequences (risk perception &amp; outcome expectations). Adolescents know the benefits of maintaining good oral health (outcome expectations).</td>
<td>- Providing information on health consequences (BCT 5.1) (e.g., written, verbal, visual): i.e., providing information on health consequences of performing the behavior) [35]. - Belief selection: i.e., using messages designed to strengthen positive beliefs, weaken negative beliefs, and introduce new beliefs [34]. - Providing scenario-based risk information: i.e., providing information that may aid the construction of an image of the ways in future loss or accident might occur [34]. - Providing reinforcement: i.e., linking a behavior to any consequence that increases the rate, frequency and probability of the behavior [34].</td>
<td>There must be a plausible scenario with a cause and an outcome.</td>
<td>The app provides information on the importance of tooth brushing as recommended in a short animated movie. The movie explains that not brushing teeth can increase the risk of getting dental diseases (how plaque can cause dental diseases) and can also affect appearance. The movie provides information on the positive outcomes of maintaining good oral health. It shows two scenarios: (1) bad oral hygiene causes white spots/lesions/dental caries; (2) good oral hygiene causes white and beautiful teeth.</td>
</tr>
<tr>
<td>Adolescents know how to brush teeth according to the 5-step method (knowledge). Adolescents feel able to prevent dental diseases and gain confidence in ability to brush teeth twice daily according to the 5-step method (action self-efficacy). Adolescents develop tooth brushing skills (5-step method): to remove all dental plaque (skills).</td>
<td>- Providing instructions on how to perform the behavior (BCT 4.1): advise or agree on how to perform behavior (includes &quot;skills training&quot;) [35]. - Demonstrating the behavior (BCT 6.1): i.e., providing an observable sample of the performance of the behavior, directly in person or indirectly (e.g., through film) includes &quot;modeling&quot; [34].</td>
<td>The adolescents must identify with the model (use a coping model instead of mastery model).</td>
<td>The adolescents with fixed orthodontic appliances demonstrates how to brush teeth correctly twice daily according to the 5-step method. The demonstration is tailored to the kind of toothbrush they use, i.e., electric or manual.</td>
</tr>
</tbody>
</table>

#### PO2 Adolescents choose/plan how to improve their tooth brushing behavior.

<table>
<thead>
<tr>
<th>Change objectives (determinant)</th>
<th>Theoretical methods/ BCTs</th>
<th>Theoretical requirements</th>
<th>Practical strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents choose to change about which they feel self-efficacious (goal-commitment &amp; action self-efficacy).</td>
<td>- Prompting intention formation: i.e., encouraging the person to decide to act on a goal [27]. - Setting graded tasks: i.e., setting easy tasks, and increasing difficulty until target behavior is performed [34].</td>
<td>The target behavior can be reduced to easier but increasingly difficult sub-behaviors.</td>
<td>The app allows the adolescents to choose the tooth brushing duration and/or frequency they would like to change and they think they can change.</td>
</tr>
</tbody>
</table>
### PO3 Adolescents prepare strategies to establish how they will change their tooth brushing behavior.

<table>
<thead>
<tr>
<th>Change objectives (determinant)</th>
<th>Theoretical methods/ BCTs</th>
<th>Theoretical requirements</th>
<th>Practical strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents plan in terms of when and where to brush their teeth (action planning).</td>
<td>- Prompt action planning (BCT 1.4): i.e., prompting detailed planning of performance of the behavior (must include at least one of context, frequency, duration and intensity) [35]. (This includes implementation intentions: prompting making if-then plans that link situational cues with responses that are effective in attaining goals or desired outcomes [34]).</td>
<td>Adolescents need to have a positive intention.</td>
<td>The app incorporates a program that helps the adolescents to form action plans. Guided by questions in the app, adolescents can specify when and where they will brush their teeth. The answers are presented as their action plan, which will state where and when they will brush their teeth. This action plan is formulated as an implementation intention (“If situation X arises, then I’ll do Y”) (The action plan is linked to the option for setting reminders).</td>
</tr>
</tbody>
</table>

### PO4 Adolescents change their tooth brushing behavior.

<table>
<thead>
<tr>
<th>Change objectives (determinant)</th>
<th>Theoretical methods/ BCTs</th>
<th>Theoretical requirements</th>
<th>Practical strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents receive support during brushing on where and for how long to brush teeth (facilitator/support).</td>
<td>- Providing practical support (BCT 3.2): i.e., advising on, arranging, or providing practical help for performance of the behavior [35]. - Providing technical assistance: i.e., providing technical means to achieve desired behavior [34].</td>
<td>The technical assistance must fit the recipient’s needs and resources.</td>
<td>The app provides technical means for achieving the desired tooth brushing behavior, i.e., it incorporates a brushing timer. This provides practical support with brushing according to the 5-step method, showing each step during brushing.</td>
</tr>
<tr>
<td>Adolescents receive cues to tooth brushing (cues to action, habit formation).</td>
<td>- Prompts/cues: i.e., introducing or defining environmental or social stimuli with the purpose of prompting or cueing the behavior. The prompt or cue would normally occur at the time or place of performance (BCT 7.1) [35].</td>
<td>Cues work best when people are allowed to select and provide their own cues.</td>
<td>The app has an option for setting reminders, which are sent as push notifications that function as “cues to action”. The adolescents will be reminded to brush their teeth at a time that fits in with their daily routine.</td>
</tr>
</tbody>
</table>

### PO5 - Providing technical assistance: i.e., providing technical means to achieve desired behavior [34].

<table>
<thead>
<tr>
<th>Change objectives (determinant)</th>
<th>Theoretical methods/ BCTs</th>
<th>Theoretical requirements</th>
<th>Practical strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolescents monitor their tooth brushing behavior and dental plaque levels (awareness, self-regulatory skills/action control).</td>
<td>- Self-monitoring of the behavior (BCT 2.3): i.e., the person monitors and records their behavior as part of a behavior change strategy [35]. - Self-monitoring of the outcome of behavior (BCT 2.3): i.e., the person monitors and records the outcome of their behavior as part of a behavior change strategy [35].</td>
<td>Commitment and motivation are required to use the self-monitoring part of the app. The data must be interpreted and used.</td>
<td>Upon installing the app in the orthodontic clinic, a dental hygienist briefly shows the adolescent how to monitor their tooth brushing and dental plaque levels. Adolescents fill out their tooth brushing frequency in the app every day. If they fail to complete the monitoring, a prompt message is sent the next day.</td>
</tr>
<tr>
<td>Adolescents examine how well their performance corresponds to agreed tooth brushing goals, and consider modifying goals accordingly (skills and goal pursuit).</td>
<td>- Reviewing behavior goal(s) (BCT 1.5): i.e., reviewing behavior goal(s) jointly with the person and considering modifying goal(s) or behavior change strategy in the light of achievement. This may lead to re-setting the same goal, to a small change in that goal, or to setting a new goal rather than (or in addition to) the first; or to no change [35]. Discrepancy between the current behavior and goal (BCT 1.6): i.e., drawing attention to discrepancies between a person’s current behavior (in term of the form, frequency, duration, and intensity of that behavior) and the person’s previously set outcome goals or action plans (goes beyond self-monitoring of behavior).</td>
<td>Requires awareness of the oral health recommendations.</td>
<td>Based on the information obtained from the brushing timer and the self-monitoring records, the app provides personal feedback once a week on whether the person’s performance corresponds to the agreed goals and asks them to consider modifying goals accordingly.</td>
</tr>
</tbody>
</table>
Adolescents monitor their dental plaque levels (awareness, self-regulatory skills) and compare it with goal (awareness, self-regulatory skills).

- Using disclosing tablets to visualize and evaluate dental plaque [35].
- Prompting self-monitoring of the outcome of the behavior (BCT 2.4): i.e., establishing a method for the person to monitor and record the outcome(s) of their behavior as part of a behavior change strategy [35].
- Providing feedback on the outcome of behavior (BCT 2.7): i.e., monitoring and providing feedback on the outcome of the behavior [34, 35].

Adolescents need to possess the subskill: identifying which dental surfaces are clean and which are covered with dental plaque.

- Once a week the app asks adolescents to use disclosing tablets to visualize the dental plaque and to take a selfie of the results. Based on the number of clicks, the app compares the number of clicks (plaque levels) with the results of the previous week, and provides feedback accordingly.

If they have difficulty attaining their tooth-brushing/dental plaque goal, adolescents identify possible solutions.

### Change objectives (determinant) | Theoretical methods/BCTs | Theoretical requirements | Practical strategies
--- | --- | --- | ---
Adolescents identify and anticipate barriers and ways to overcome them (coping planning, action control) | Problem solving/prompt barrier identification (BCT 1.2): i.e., analyzing, or prompting the person to analyze, factors influencing the behavior; and generating or selecting strategies that include overcoming barriers and/or facilitators (includes “relapse prevention” and “coping planning”)[34, 35]. | Barrier identification without solutions is not sufficient. | If a person’s goal has not been achieved, volitional help sheets will be presented to help them identify barriers preventing them from proper tooth brushing and their possible solutions. The results of this volitional help sheets are presented as their coping plan, which will be stored in the main page of the app. This coping plan is formulated as an implementation intention (“If difficult situation X arises, then I’ll do Y”).

Adolescents gain confidence to deal with possible barriers (coping self-efficacy). | Setting implementation intentions: i.e., prompting the making of if-then plans that link situational cues with responses that are effective in attaining goals or desired outcomes [34]. | Requires identification of the barriers and possible solutions/coping responses. | Adolescents enlist others to help overcome barriers (social influences)

Mobilizing social support: i.e., advising on, arranging, or providing social support for performance of the behavior [34]. | Adolescents are motivated to ask significant others. | If needed, adolescents are guided in asking significant others to support tooth brushing. When necessary, the app suggests asking parents and/or orthodontists for support, e.g., helping or demonstrating how to brush teeth.

Adolescents maintain the desired tooth brushing behavior.

### Change objectives (determinant) | Theoretical methods/BCTs | Theoretical requirements | Practical strategies
--- | --- | --- | ---
Adolescents gain confidence in maintaining tooth brushing behavior (maintenance self-efficacy). | Belief selection: i.e., using messages designed to strengthen positive beliefs, weaken negative beliefs, and introduce new beliefs [34]. | Before choosing the beliefs on which to intervene, the individual’s current attitudinal, normative, and efficacy beliefs should be investigated. Gain-framed messages are more readily accepted and prevent defensive reactions. | The app provides positive personal text messages about favorable outcomes and the benefits of tooth brushing, i.e., personal motives which are asked by the app when starting the app.

Adolescents feel positive about tooth brushing (outcome expectations). | Framing: Using gain-framed messages emphasizing the advantages of performing the healthy behavior [34]. | | |

Adolescents believe that long term benefits can be achieved by maintaining tooth brushing over time (attitude). | | | |

BCT: Behavior Change Technique [36]; PO: Performance objectives.