The WhiteTeeth app

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

Scheerman, J.F.M.

CHAPTER 6

The effectiveness of the WhiteTeeth app, a theory-based oral health promotion program for adolescent orthodontic patients

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Scheerman JFM, van Meijel B, van Empelen P, Verrips GHW, van Loveren C, Twisk JWR, Pakpour AH, van Den Braak MCT, Kramer GJC.

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ABSTRACT

Background: The aim of this study was to evaluate the effectiveness of the WhiteTeeth smartphone app, a theory-based mobile health (mHealth) program for oral health behavior and oral hygiene in adolescent orthodontic patients. Integrating several behavior change techniques targeting oral health behaviors and their psychosocial factors, the app combined oral health education with an automatic coaching program.
Methods: In this parallel randomized controlled trial, adolescents with fixed orthodontic appliances were recruited from two orthodontic clinics in the Netherlands. The data of 132 adolescents were collected during three orthodontic check-ups: at baseline (T0), at 6-week follow-up (T1), and at 12-week follow-up (T2). After baseline assessment, randomization was performed at patient level. The intervention group was given access to the WhiteTeeth app in addition to usual care (n=67). The control group received usual care only (n=65). The oral hygiene outcomes were the presence and the amount of dental plaque (measured according to a modified Silness and Loë Plaque Index); and the total number of sites with gingival bleeding (measured according to the Bleeding on Marginal Probing Index). Oral health behavior and its psychosocial factors (secondary outcomes) were measured through a digital questionnaire. We performed linear mixed model analyses to determine the intervention effects.
Results: At 6-week follow-up, the intervention led to a significant decrease in gingival bleeding (B=-3.74; 95%CI -6.84 to -0.65), and an increase in the use of fluoride mouth rinse (B=1.93; 95%CI 0.36 to 3.50). At 12-week follow-up, dental plaque accumulation (B=-11.32; 95%CI -20.57 to -2.07) and the number of sites covered with plaque (B=-6.77; 95%CI -11.67 to -1.87) had been reduced significantly more in the intervention group than in the control group. At both follow-ups, significant effects were found in favor of the intervention group for the intention to use mouth rinse (T1 B=0.56; 95%CI 0.15 to 0.96; T2: B=0.42; 95%CI 0.01 to 0.83) and coping planning regarding tooth brushing (T1 B=0.56; 95%CI 0.15 to 0.96; T2 B=0.27; 95%CI 0.03 to 0.51).
Conclusion: The results show that adolescents with fixed orthodontic appliances can be helped to improve their oral hygiene when usual care is combined with a smartphone app that provides oral health education and automatic coaching. After the intervention period, however, adolescents' oral health behavior and oral hygiene was still not optimal in either group. This indicates the need for improved interventions for promoting better oral health behavior and oral hygiene.
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Keywords: app, mHealth, oral health promotion, oral health behavior, and oral hygiene.

INTRODUCTION

While approximately 60% of young adults in the Netherlands receive orthodontic treatment during adolescence, fixed orthodontic appliances have an unfortunate side-effect: they make oral hygiene procedures more difficult [1]. Failure to practice good oral hygiene results in prolonged accumulation of biofilm (dental plaque), which potentially increases levels of cariogenic bacteria such as Streptococcus mutans. These produce acids that cause enamel demineralization [2, 3]. As a result, many patients with fixed appliances have dental caries, specifically white spot lesions, which can lead to aesthetic problems that potentially cancel out the beneficial effect of the orthodontic treatment [4-8].

To prevent the development and/or the progression of dental caries, orthodontic healthcare providers recommend their patients to adhere to a good oral hygiene regimen involving the use of fluoride-containing mouth rinses, toothpastes, and varnishes [9]. However, adherence to these recommendations is low, and oral hygiene in adolescent orthodontic patients is often inadequate [10,11]. This indicates a need for interventions to improve oral health behavior and oral hygiene in this special risk population.

Many health promotion programs that successfully changed health behavior included methods that targeted different stages of the behavior change process, i.e. the process of behavioral initiation and maintenance [12,13]. Examples of methods targeting behavior initiation include providing health risk information and demonstrating how to perform the behavior. Examples of methods targeting the process of behavioral maintenance are: self-monitoring of behavior and behavioral outcomes, prompting barrier identification, setting action and coping plans, and reviewing behavioral goals [12-15]. However, these methods have only rarely been applied in orthodontics [11]. In orthodontics, studies have combined mobile-health technology with oral health behavioral support—particularly sending text messages to deliver prompts or oral health information. These interventions had a positive effect on oral hygiene during fixed orthodontic treatment [16-23]. In our study we chose a combination of changing health behavior and using mobile health technology. We took a systematic approach to designing the WhiteTeeth app, a smartphone-delivered oral health promotion program for adolescents with fixed orthodontic appliances [12]. Combining behavioral change methods with the advantages of mobile technology, the app provided oral health education and an automatic coaching program intended to help these users maintain good oral health behavior and oral hygiene.

To determine the app's effectiveness, we examined its effect on objectively-measured dental plaque and marginal bleeding (primary outcomes); and self-reported oral health behaviors and their psychosocial factors (secondary outcomes). We

hypothesized that dental plaque and marginal gingival bleeding would be reduced more in participants who combined use of the app with usual care than in controls.

METHODS

This two-armed, parallel-group, single-blinded randomized controlled trial (RCT) tested the effect of the WhiteTeeth app against a usual care group in 12 to 16-year olds with fixed orthodontic appliances. Our study design has been published in detail elsewhere [24]. The study was approved by the Medical Ethics Committee (METC) at VU Medical Centre in Amsterdam (protocol. nr. 2016.162). The trial was registered with the Dutch Trial Register (www.trialregister.nl NTR6206: 20 February 2017), and was conducted and reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines [27].

Participants

The study population consisted of adolescents with fixed orthodontic appliances visiting orthodontic clinics in Alkmaar and Leiden, two cities in the Netherlands. These adolescents could participate in the study if they met the eligibility criteria (see Table 1). All eligible adolescents were invited to participate by their dental-care provider—who was not further involved in the study—during a regular check-up from October 2016 to October 2017. Those who were willing to participate received an invitation letter containing information on the study and an informed consent form. Baseline assessments were scheduled after adolescents and their parents had returned the informed consent form. Data collection took place in the period from February 2017 to October 2017. After the completion of the baseline assessments, an independent researcher used a random-sequence generator (http://www.random.org) to randomize the adolescents into either the control or intervention group.

Table 1. Eligibility criteria.

Adolescents could participate if they met the following eligibility criteria:
- They were boys or girls aged 12 to 16.
- For at least 6 weeks, they had had maxillary and mandibular fixed orthodontic-appliance therapy, which consisted of bonding at least premolar-to-premolar with edgewise appliances and their modifications.
- They had not been scheduled for removal of fixed orthodontic treatment before the end of the study.
- They had no physical and/or mental disabilities that impeded their ability to perform their own oral hygiene activities.
- They had not been engaged in any other oral health education or research program.
- They did not have enamel or dentine dysplasia and/or craniofacial malformation (e.g. cleft).
- They had a sufficient command of the Dutch language.
- They possessed a smartphone with IOS ≥7 or Android ≥ 4.1 software.
- Patients and their parents were willing and able to give informed consent.
- Patients did not use medication such as antibiotics or antibacterial mouth rinses that might affect plaque accumulation.

Those assigned to the control group received usual care, which consisted of routine oral health education and oral health instructions during their visits for orthodontic treatment. To protect against observer bias, the outcome assessors and the dental-care providers who provided the orthodontic care—including the usual preventative advice—were blinded. This was achieved through the use of two separate rooms: while the outcome assessors performed their examinations in the first room, an independent researcher allocated the intervention in the second room. Per visit, researchers requested the adolescents not to talk with the assessors and dental-care providers about their treatment allocation.

The intervention: the WhiteTeeth app

It is increasingly recognized that interventions should be based on theory, and should therefore be guided by intervention mapping [26, 27]. Intervention mapping is a protocol for developing theory-based and evidence-based health promotion programs, whose function is to help health promoters develop the best possible intervention [26]. Previously, we applied this protocol to the systematic development of the WhiteTeeth application (app) in a way that would improve oral hygiene in adolescents with fixed orthodontic appliances [12]. A detailed description of the systematic development and of the content and preliminary testing of the WhiteTeeth app has been published elsewhere [12].

The app was designed on the basis of the Health Action Process Approach (HAPA) theory, which has been shown to be a useful approach to understanding the oral health behaviors of adolescents with fixed orthodontic appliances [10,28]. Using behavior change techniques (BCTs) that target the psychosocial factors outlined by the HAPA theory, the app focused mainly on improving oral health behavior, and thereby reducing dental plaque levels and gingival bleeding.

Participants randomized to the intervention group were asked to download the WhiteTeeth app, which was available free of charge in the App store and Google Play store, and was locked with a login code. Each participant received a unique personal login code for the app. An independent researcher gave brief instructions and information on how to use the app and on how to share their user data with the research team. Afterwards, the participants received an email containing these instructions and information.

Upon opening the WhiteTeeth app, participants were required to answer registration questions and to provide personal details on their oral health behavior and their motivation for maintaining good oral health. The app used this information to create positive reinforcement and to provide feedback on the participants' oral health performance. During registration, the app asked participants to use disclosing tablets (which were provided at baseline) and to take a selfie of their teeth on which any dental plaque had been disclosed red. Next, the app asked the participants to register the amount of plaque by clicking the disclosed areas on the selfie (*BCT: self-monitoring of behavioral outcomes* [29,30]). After interpreting the amount of plaque on the basis of the number of clicks, the app provided tailored feedback on the basis both of this plaque assessment and of the answers to the registration questions on oral health procedures. This feedback was provided as positive reinforcement regarding participants' behavior, as oral health education, and/or as instructions in short videos (*BCT: providing information on health consequences, and demonstrating the desired behavior* [31,32]).

Next, the app invited the participants to set a particular goal regarding oral health behavior (*BCT: Goal setting* [33]) and to formulate when and where they would perform the oral health behavior (*BCT: implementation intentions* [34]). The app provided an option for setting the time at which they wished to receive daily push notifications to remind them of their oral health behavior tasks, and then to monitor them (*BCT: behavioral goal reminders* [16-18]).

Every day throughout the 12-week intervention period, push notifications were sent instructing users to enter whether or not they had accomplished their daily oral health behavior tasks (*BCT: self-monitoring of behavior* [35,36]), and to remind them to use the brushing timer when brushing their teeth. As well as showing where and how to brush teeth as recommended [12], the timer showed the time elapsed during

brushing (*BCT: practical support* [32]). When users had completed brushing, the app provided positive reinforcement.

Each week, the app asked users to evaluate their dental plaque levels by following the same procedure as in the registration phase: using a disclosing tablet, taking a selfie of their teeth, and clicking the disclosed areas on the selfie *(BCT: self-monitoring of behavioral outcomes* [36]). On the basis of the information registered on the amount of plaque and of the activities reported daily over the previous week, the app concluded whether the user's goals had been attained. Users were then invited to adjust their goals. If they had failed to attain their goals, they were invited to formulate coping plans, i.e., "if-then" plans specifying how they could deal with difficult situations (*BCT: coping planning* [37]). For this purpose, the app contained volitional sheets, i.e., sheets outlining pre-established difficult situations and solutions.

Outcome measures

The outcome measures were collected through clinical assessments and self-administered digital questionnaires. At baseline (T0), and at six weeks (T1) and twelve weeks (T2) of follow-up, the data were collected before the orthodontic check-up.

The primary study outcomes were the amount of plaque and the total number of gingival bleeding sites in the incisors, canines and first premolars of the maxilla and mandible. A modified Silness and Loë plaque index was used to measure the amount of plaque on the buccal surfaces [38]. The buccal surfaces of the first premolars, canines and incisors were divided into four sites according the position of the orthodontic bracket: mesial, distal, gingival and incisal to the bracket (Fig. 1) [38]. Each of the four sites of the buccal tooth surface was given a score ranging from 0 to 3, where 0 indicated the absence of dental plaque, 1 indicated no plaque visible but an accumulation of soft deposit on a probe when used to clean the surface, 2 indicated a moderate accumulation of soft deposit on the tooth that could be seen with the naked eye, and 3 indicated an abundance of soft matter on the tooth.

For the analysis, the scores per site were summed to obtain a total score for the amount of dental plaque accumulation per patient. Higher scores indicated greater accumulation. The range was from 0 to 192 (16 elements*4sites*3 scores). To explore the effect on the presence of plaque in the mesial, distal, gingival and incisal sites, we dichotomized the plaque scores, with 0 indicating the absence of dental plaque and 1 indicating the presence of dental plaque. The score for the number of sites covered with plaque ranged thus from 0 to 16 (16 elements) per site and from 0 to 64 per patient (16 elements*4 sites).

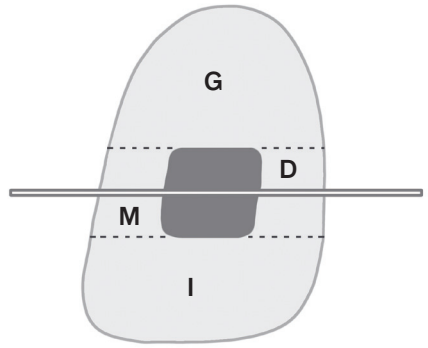

Fig.1. The buccal surfaces of the first premolars, canines and incisors were divided into four sites in relation to the position of the orthodontic bracket (G gingival, M mesial, D distal, I incisal).

Gingival bleeding was assessed using the Bleeding on Marginal Probing index (BOMP), the condition of the gingiva being scored according to the method described by Van der Weijden et al (1991) [39]. The mesio-buccal, buccal and disto-buccal sites of the buccal surfaces of the first premolar, canines and incisors were assessed to determine whether probing elicited marginal bleeding (score 1) or not (score 0). For the analysis, all scores were summed to obtain the total number of bleeding sites per patient. Higher scores indicate more gingival bleeding. The outcome variable ranged from 0 to 48 (16 teeth * 3 sites).

To ensure the reliability of the clinical measurements, the clinical examiners were trained and calibrated by an experienced examiner. Inter-examiner reliability was assessed using the intra-class correlation coefficient (ICC) with a two-way random-effects model. As a measurement of inter-examiner agreement, the ICCs in 10% of the measurements of the study population were 97.6% for the mean plaque score per patient and 93.2% for the mean bleeding score.

The secondary study outcomes were self-reported oral health behaviors and their psychosocial factors (HAPA factors). To measure these outcomes, we used a self-administered digital questionnaire containing questions with both single and multiple response items (see the study protocol for the full questionnaire) [24]. The questionnaire included questions on the frequency of oral health behaviors with which the following were used: a toothbrush, a proxy brush, a toothpick, mouth rinse, and other dental aids (such as dental floss). It used the following 7-point scale: 1: less than twice a month or never, 2: twice a month, 3: once weekly, 4: two to three times weekly; 5: once daily, 6: twice daily, and 7: three times daily or more. For the analysis,

these response options were recalculated to establish the weekly frequencies of each of the oral health-related activity (ranging from 0 to 24.5). Subsequently, the weekly frequencies for the use of each of the dental aids or products were summed to obtain a total oral health behavior score that ranged from 0 to 122.5. Higher scores indicate a higher frequency of oral health-related activities. Self-reported tooth brushing frequency and tooth brushing duration were measured on the basis of two open questions, i.e., "In the last four weeks, how many times have you brushed your teeth per day?" and "How much time do you spend on brushing your teeth at a time?". The following psychosocial factors—HAPA factors—were assessed: risk perception, action self-efficacy, intention, maintenance self-efficacy, recovery self-efficacy, action control, action planning, and coping planning, social influences, outcome expectancies. Risk perception was assessed on 5-point scales ranging from "very low" (1) to "very high" (5). Coping planning and action planning were assessed on 4-point scales ranging from "no plan" (1) to "a very clear plan" (4). For the remaining variables, a 5-point scale was used, ranging from "totally disagree" (1) to "totally agree" (5). Cronbach's alpha (α) for all psychosocial factors held acceptable values (0.70-0.95) [40].

Covariates

The following variables were regarded as potential confounders or effect modifiers and collected at baseline: 1.) age (in years); 2.) sex (boy/girl); 3.) level of education (primary education, prevocational education; senior general secondary or pre-university education); 4.) cultural background (Dutch or other); 5.) smoking status (smoker or non-smoker); and 6.) the number of times of exposure to the acids or sugars in foods and/or drinks between main meals (times per day). Orthodontic patient files also provided information on baseline covariates: 7.) the type of orthodontic bracket used (e.g. self-ligating or conventional brackets); 8.) the treatment duration (in days).

Use of the WhiteTeeth app and its usability

App usage data was collected during the 12-week intervention period. Participants were asked to use the WhiteTeeth app to send their user data weekly from their smartphone via to the database. At 6-week and 12-week follow-up, all participants in the intervention group were reminded to send their user data via the app. Data files were imported into an Excel-file and processed into a format suitable for SPSS. This process was undertaken by an independent researcher who had no involvement in data collection or data analysis.

After the 12-week follow-up period, a digital questionnaire was conducted to determine the usability of the app and the user's perceptions of several components of the app. For this purpose we used the System Usability Scale (SUS), measuring subjective assessments of the app's usability [41]. The SUS-scale ranges form 0-10, with responses ranging from

"strongly agree" to "strongly disagree". A SUS-score above 68 was considered to be above average. This questionnaire has been published elsewhere [24].

Statistical analysis

Continuous data are presented as means (M) with standard deviations (SD) and categorical data as frequencies and percentages. Descriptive statistics were used to describe the use of components of the app. The independent sample t-test and the chi-square test were used to compare the baseline characteristics of drop-outs and completers in the total sample. Linear mixed models were used to analyze the effects of the WhiteTeeth app and to take account of the correlated observations within the participant. To compare the outcome (dental plaque, gingival bleeding, oral health behaviors and their psychosocial factors) between the intervention and control groups, we performed intention-to-treat analyses. To take account of differences in baseline values in all analyses, the outcome of interest was adjusted for the baseline value of that particular outcome. With mixed model analyses, the intervention effect was evaluated at different follow-up times. This was done by adding the interaction between the condition and time to the model. Two models were constructed: (1) crude models; (2) models adjusted for covariates. Since linear mixed model analysis handles missing observations caused by drop-out, no additional action were undertaken to handle missing data.

A two-tailed significance level of 5% was considered to be statistically significant in all analyses. The analyses were conducted with the Statistical Package of Social Sciences (SPSS) version 22.0 (IBM Corp, Armonk, NY, USA).

RESULTS

As figure 2 shows, 132 of the 230 eligible adolescents with fixed orthodontic appliances agreed to participate; they provided informed consent, attended baseline, and were randomly assigned to one of the two experimental arms (response rate 57%). Five patients dropped out of the intervention group, and three patients out of the control group. One patient in each group dropped out because their appliances had to be removed prematurely due to poor oral hygiene. Due to technical complications involving the tablet on which the T0 questionnaire was filled in, the total number of participants who completed all three questionnaires was 121 (92%).

Between T0 and T1, the mean number of weeks (SD) between each appointment was 6.2 weeks (1.4) for the intervention group and 6.2 weeks (1.1) for the control group (p=0.997). Between T1 and T2, it was 6.6 weeks (2.1) for the intervention group and 6.7 weeks (2.3) for the control group (p=0.962).

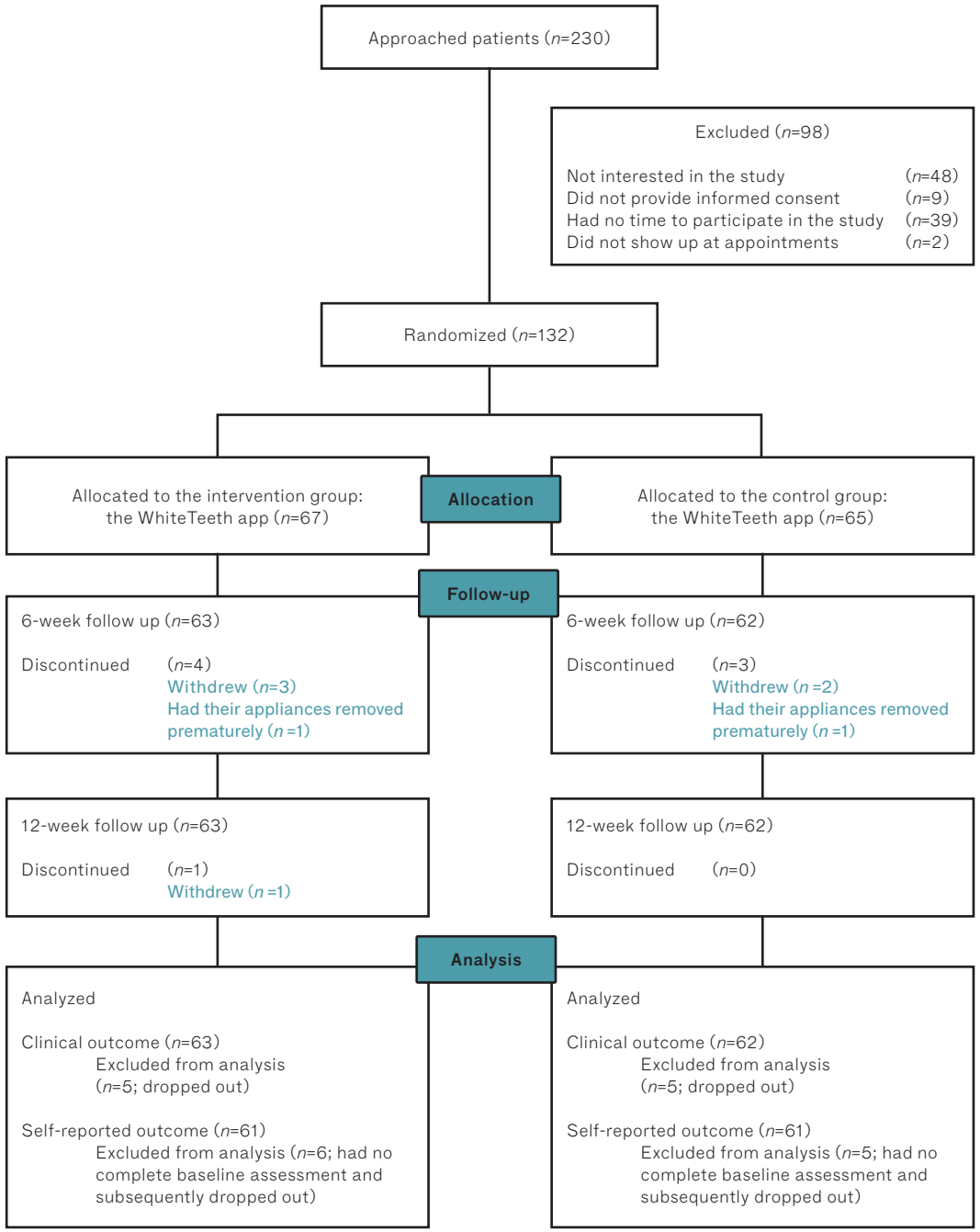

Fig. 2. Flowchart of the participants throughout the trial.

Table 2. Patients' characteristics at baseline.

Characteristic	Intervention group (n=67)	Control group (n=65)
Age (years)[a]	13.2 (1.01)	13.5 (0.97)
Girl (yes)[b]	41 (61.2%)	32 (49.2%)
Education level[b] *(Using the standard Dutch abbreviations)*		
- Primary education	7 (10.4%)	2 (3.1%)
- Prevocational education - Practical pathway *(PP VMBO)*	7 (10.4%)	6 (9.2%)
- Prevocational education - Theoretical Pathway *(TP VMBO)*	16 (23.9%)	14 (21.5%)
- Senior general secondary education *(HAVO)*	17 (25.4%)	23 (35.4%)
- Pre-university education *(VWO)*	20 (29.9%)	20 (30.8%)
Cultural background[b]		
- Dutch	63 (94.0%)	56 (86.2%)
- Moroccan	4 (6.0%)	5 (7.7%)
- Other	0 (0%)	4 (6.2%)
Smoking (no)[b]	67 (100%)	65 (100%)
Conventional brackets (yes)[b]	16 (24.6%)	22 (32.8%)
Exposure to the acids and/or sugars in foods and/or drinks between main meals (times per day)	3.6 (1.80)	3.5 (2.16)
Duration at baseline of treatment with fixed orthodontic appliances (days)[a]	401.0 (212.1)	419.0 (277.2)
Oral health behavior score (0-122.5)[a]	20.9 (9.3)	20.1 (8.2)
Plaque index (S&L; 0-192)[a]	70.8 (29.6)	75.3 (34.3)
Number of gingival bleeding sites (0-48)[a]	27.8 (8.9)	28.1 (8.3)

[a] mean (SD), [b] n (%)

Due to technical complications, occasional malfunctions meant that the user data—including selfies—was not always sent during the intervention period. For this reason, less user data was available than expected. But according to the user data we received, 40 participants (65%) sent their user's data an average of 4.94 times (SD=5.2) to a secure server owned by the Academic Centre for Dentistry Amsterdam. After 6 weeks, most patients used the app less often. In total, reminders were set by 7 participants for brushing, by 9 participants for rinsing, by 16 for self-monitoring of behavioral tasks, and by 11 for taking a selfie. During the intervention period, 20 participants used the brushing timer an average of 9.61 times (SD=27.8). In total, 38 participants took at least one selfie with the app; the mean number of selfies taken per person was 6.63

(SD=4.46). Thirty-six participants entered action plans into the app, and seven used the volitional sheets to set a coping plan. Thirty-four participants watched at least once the video on dental plaque, and/or on cleaning their teeth with a manual toothbrush, an electric toothbrush and/or proxy brushes. Personal appearance and attractiveness (white teeth) were given as the commonest motives for cleaning their teeth. The mean SUS was 75 (range 0-100), which indicated a good score for usability.

Table 2 presents the baseline demographic and clinical characteristics of the study sample. Comparison of the baseline characteristics of patients who completed the study and those who dropped out before the last assessment show that completers scored significantly higher on the oral health behavior score (mean (SD) total sample = 20.67 (8.97); Drop-out= 17.88 (2.67); p=0.04).

The intervention effects on oral hygiene

Table 3 shows descriptive information on the oral hygiene outcomes for the two groups at baseline, at 6-week follow-up, and at 12-week follow-up. It also shows the crude and adjusted intervention effects on oral hygiene at both 6-week and 12-week follow-up. At 6-week follow-up, the intervention effect on the total amount of dental plaque (B=-6.86; 95%CI -16.05 to 2.34) and the total sites covered with plaque (B=-4.83; 95%CI -9.69; 0.04)) was not significant. Nonetheless, at 12-week follow-up, the reductions in dental plaque accumulation (B=-11.32; 95%CI 20.57 to -2.07) and in the presence of dental plaque (B=-6.77; 95%CI -11.67 to -1.87) were significantly greater in patients in the intervention group than in the controls: while, on average, plaque was present on 62% of teeth in the intervention group, it was present on 73% of teeth in the control group. Explorative analysis showed that the intervention had significantly affected the dental plaque on the mesial, distal and gingival sites to the orthodontic bracket, but not on the site that was incisal to the bracket.

Regarding the intervention effects on gingival bleeding, bleeding scores had improved more in participants in the intervention group than in controls at 6 weeks of follow-up (B=-3.74; 95%CI -6.84 to -0.65). At 12 weeks of follow-up, however, the intervention effect was no longer significant (B=-1.89; 95%CI -5.00 to 1.22).

The intervention effects on oral health behavior and its psychosocial factors

Table 4 shows the descriptive information and the results of the mixed model analyses for the oral health behaviors. The only significant intervention effect was for fluoride use at the 6-week follow-up; it favored the intervention group (B=1.93; 95%CI 0.36 to 3.50). No significant intervention effects were found for the oral health behavior score, tooth brushing (frequency and duration) and proxy brush usage.

With regard to the psychosocial factors, significant adjusted effects were found for coping-planning regarding tooth brushing (T1: B=0.27; 95%CI 0.03 to 0.51;T2: B=0.27; 95%CI 0.03 to 0.51; p=0.028) and intention towards fluoride mouth-rinse use (T1 B=0.56; 95%CI 0.15 to 0.96; T2 B=0.42 95%CI 0.01 to 0.83) at both 6-week and 12-week follow-up. Although not significant, the scores on most psychosocial factors at 12-week follow-up were better in the intervention group than in the control group (data not shown).

DISCUSSION

This randomized controlled trial aimed to test the effect of the WhiteTeeth app on oral health behavior and oral hygiene in adolescents with fixed orthodontic appliances. The app incorporated many behavior change techniques, targeting not only oral health behavior but also the psychosocial factors that are associated with this behavior and had been identified through the HAPA theory [12]. The behavior change techniques it incorporated included coaching to set goals, action plans and reminders; self-monitoring of oral health behavior and dental plaque; providing feedback and practical support; reviewing behavioral goals and creating coping plans.

Relative to the usual care group, the WhiteTeeth app was associated with significant reductions in gingival bleeding at 6 weeks of follow-up and in dental plaque at 12 weeks of follow-up. Although the app was not effective in changing tooth brushing frequency and duration, the decrease in dental plaque reflects a change in brushing pattern, as the number of sites covered with plaque decreased significantly. For example, a person may initially have focused on the incisal sites to the exclusion of the distal sites. At both follow-ups, the app was also effective in changing coping planning regarding tooth-brushing.

Previously, only two studies evaluated the effectiveness of a smartphone app for oral health promotion in orthodontic patients [22, 23]. In the first, Zotti et al. [22] evaluated a WhatsApp-based program that combined instructions on maintaining oral hygiene during orthodontic treatment with the use of a chat room named the “Brush Game”, in which patients could share information, pictures and movies on oral hygiene and orthodontic treatment. At, 9, and 12 months, the WhatsApp-based program had been effective in improving both the oral hygiene and oral health of adolescents with fixed appliances: at 12 months, patients participating in the chat room had significantly lower values on the plaque index (p <0.0001) and gingival index (p <0.05), and also a lower incidence of new white spot lesions or caries than those in the control group (control group: 40% vs. app group: 15.5%; p <0.0001).

Table 3. Descriptive information and the effects of the intervention on dental plaque and gingival bleeding of the first premolars, canines and incisors around the brackets (n=124).

		Mean (Standard deviation)				T1			T2		
Outcome measures (scale)		**T0**	**T1**	**T2**	**Effects**	**B**	**95% CI**	***p***	**B**	**95% CI**	***p***
Total amount of dental plaque accumulation according the modified Sillness and Loë score (0-192)	Intervention	70.79 (29.56)	52.41 (29.02)	54.63 (26.93)	Crude [a]	-7.95	-16.81; 0.90	0.078	-13.49	-22.37; -4.62	0.003
	Control	75.34 (34.27)	62.97 (25.71)	70.42 (30.72)	Adjusted [b]	-6.86	-16.05; 2.34	0.143	-11.32	-20.57; -2.07	0.017
Total sites covered with plaque (0-64)	Intervention	45.04 (12.43)	38.02 (15.73)	39.66 (14.93)	Crude	-4.94	-9.44; -0.44	0.032	-6.91	-11.42; -2.40	0.003
	Control	45.40 (14.35)	43.39 (12.20)	46.76 (12.03)	Adjusted	-4.83	-9.69; 0.04	0.052	-6.77	-11.67; -1.87	0.007
The number of mesial sites covered with plaque (0-16)	Intervention	12.77 (3.55)	11.30 (4.42)	11.53 (4.10)	Crude	-1.33	-2.57; -0.09	0.036	-1.88	-3.13;-0.64	0.003
	Control	12.98 (3.78)	12.81 (3.36)	13.58 (3.36)	Adjusted	-1.36	-2.71; -0.01	0.048	-1.85	-3.22;-0.49	0.008
The number of incisal sites covered with plaque (0-16)	Intervention	6.55 (4.34)	5.35 (4.43)	6.02 (4.24)	Crude	-0.86	-2.29; 0.57	0.237	-1.20	-2.63; 0.23	0.101
	Control	7.26 (4.70)	6.45 (4.19)	7.44 (4.37)	Adjusted	-0.87	-2.44; 0.69	0.271	-1.25	-2.82; 0.32	0.118
The number of distal sites covered with plaque (0-16)	Intervention	13.45 (2.94)	11.86 (4.45)	11.90 (4.45)	Crude	-1.35	-2.63; -0.07	0.039	-1.82	-3.11; -0.54	0.006
	Control	13.18 (3.67)	13.15 (3.09)	13.63 (3.35)	Adjusted	-1.11	-2.53; 0.32	0.127	-1.53	-2.96;-.091	0.037
The number of gingival sites covered with plaque (0-16)	Intervention	12.27 (3.69)	9.51 (4.47)	10.21 (4.25)	Crude	-1.46	-2.79; -0.14	0.031	-2.06	-3.39; -0.73	0.003
	Control	11.97 (3.95)	10.98 (3.96)	12.11 (3.49)	Adjusted	-1.51	-2.93; -0.09	0.038	-2.15	-3.58;-0.71	0.004
Bleeding on marginal probing (0-48)	Intervention	27.81 (8.94)	23.46 (9.34)	24.61 (10.07)	Crude	-2.32	-5.31; 0.67	0.128	-2.44	-5.45; 0.56	0.110
	Control	28.11 (8.25)	26.48 (10.12)	27.63 (8.60)	Adjusted	-3.74	-6.84; -0.65	0.018	-1.89	-5.00; 1.22	0.232

B: mean difference in outcome between the two groups; CI: confidence interval. [a] The crude effects are adjusted for baseline values of the outcome of interest; [b] The adjusted effects are adjusted for baseline values of the outcome of interest and for sex, age, education level, type of toothbrush, oral health behavior, cultural background and the duration of orthodontic treatment.

Table 4. Descriptive information and the effects of the intervention on oral health behaviors (n=121).

		Mean (standard deviation)				T1			T2		
Outcome measures (scale)		**T0**	**T1**	**T2**	**Effects**	**B**	**95% CI**	***p***	**B**	**95% CI**	***p***
Oral health behavior score (0-122.5)	Intervention	20.89 (9.24)	22.60 (12.06)	22.50 (10.59)	Crude [a]	2.37	-0.72; 5.46	0.131	0.59	-2.51; 3.66	0.707
	Control	20.08 (8.21)	20.74 (9.27)	22.00 (8.88)	Adjusted [b]	2.67	-0.72; 6.06	0.191	0.93	-2.48; 4.34	0.592
Tooth-brushing frequency (times per day)	Intervention	1.90 (0.40)	1.92 (0.41)	1.93 (0.36)	Crude	-0.04	-0.15; 0.08	0.530	-0.01	-0.12; 0.10	0.874
	Control	1.90 (0.40)	1.97 (0.39)	1.97 (0.36)	Adjusted	-0.07	-0.18; 0.04	0.233	-0.02	-0.14; 0.09	0.685
Tooth-brushing duration (minutes per session)	Intervention	2.58 (1.04)	2.79 (1.09)	2.74 (1.02)	Crude	0.26	-0.02; 0.55	0.073	0.16	-0.13; 0.45	0.268
	Control	2.50 (1.01)	2.50 (0.98)	2.43 (0.87)	Adjusted	0.29	-0.03; 0.60	0.071	0.13	-0.19; 0.45	0.413
Proxy brush use (times per week)	Intervention	4.24 (5.22)	3.74 (5.29)	4.28 (5.55)	Crude	0.30	-0.96; 1.56	0.641	1.13	-0.14; 2.39	0.081
	Control	3.26 (4.46)	2.83 (3.73)	2.48 (3.42)	Adjusted	0.65	-0.65; 1.95	0.326	0.19	-0.18; 1.58	0.777
Fluoride mouth rinse use (times per week)	Intervention	2.73 (4.78)	4.08 (4.97)	3.46 (4.27)	Crude	1.72	0.20; 3.23	0.026	0.17	-1.35; 1.69	0.822
	Control	2.41 (4.04)	2.94 (5.07)	3.63 (5.64)	Adjusted	1.93	0.36; 3.50	0.017	0.36	-1.22; 1.94	0.654

B: mean difference in outcome between the two groups; CI: confidence interval. [a] Crude effects are adjusted for baseline values of the outcome of interest; [b] Adjusted effects are adjusted for baseline values of the outcome of interest and sex, age, education level, cultural background and the orthodontic treatment duration.

In the second study, a mobile app had been designed by Alkadhi et al.: it consisted of videos of oral hygiene instructions and text messages encouraging patients to practice oral hygiene tasks [23]. Controls and patients allocated to the app all received traditional oral health promotion in an orthodontic clinic. The study, in adolescents in Saudi Arabia, showed that the app had reduced the dental plaque and gingival indices more effectively ($p<0.05$) after 4 weeks of follow-up than verbal oral hygiene instructions had [23].

While our study corroborates these findings, it also goes beyond previous studies by using behavioral theory for the program design, and thus by targeting the underlying factors of oral health behavior and by evaluating the effects on these factors. By doing so, this study contributes to research involving the understanding of oral health behavior. In addition, while the researchers in the other studies provided little detail on the content of their app, we previously published a comprehensive description of the intervention content and its incorporated behavior change techniques [12]. By adding to the limited evidence-base on the effectiveness of theory-based interventions targeting oral hygiene in adolescent orthodontic patients, this will aid researchers to design programs that are even more effective [11].

The evaluation of orthodontic oral health promotion programs has focused mainly on preventing demineralisation by improving oral hygiene procedures during fixed appliance orthodontic treatment [11,22,23]. Interestingly, however, no studies have investigated the effect of oral health promotion targeting the use of fluoride mouth rinses. Our study showed that, after 6 weeks of follow-up, the app was effective in improving not only the intention to use fluoride mouth rinse, but also its actual use. However, at 12-week follow-up, only the effect on the intention was still significant. The attenuated effect on the mouth rinse use may have been due to the fact that, after 6 weeks, most patients used the app less often.

Unfortunately, due to technical problems that occurred during the intervention period, data on the use of the various components was not reliable, as we did not receive all user's data. For example, data on creating coping plans regarding fluoride mouth rinse was not registered for any of the patients, and some patients were unable to send their data via the app because they did not install the e-mail function on their phone. These malfunctions prevented us from detecting the extent of compliance with the intervention components and from identifying which component or behavior change technique was responsible for producing changes in the outcomes, or whether there was a synergistic effect of all behavior change techniques working together. Since the launch of our app in 2016, the consumer market for oral health apps has expanded, bringing many new features, such as connections to a toothbrush via bluetooth or sound-detection, sensors that detect and record the brushing position, and options for sharing oral care activity with a dental-care provider. These tools offer

opportunities for evaluating and self-monitoring oral hygiene more accurately, which may promote the development of self-regulation skills and successful maintenance of oral health. However, the evidence base for the current range of effective interventions is still very limited, and more research is needed to determine the best ways to leverage consumer-based mobile-health technologies and combine them successfully with proven behavior change techniques. Similarly, particular attention should be paid to strategies for involving parents effectively, as previous research has shown promising results regarding the effectiveness of parents' involvement in changing adolescents' health-related behavior [42]. Future studies might thus examine the effectiveness of using the app to share and evaluate adolescents' goals and oral hygiene with parents and/or the dental care provider.

Conclusion

The use of a smartphone app as an adjunct to usual care may be a viable method of improving oral health promotion in adolescent orthodontic patients. The findings of our randomized controlled trial show that the WhiteTeeth app was effective in reducing dental plaque in adolescents with fixed orthodontic appliances. However, after the intervention period, the oral hygiene of patients in usual care and the app group was still not optimal. This indicates the need to improve oral hygiene programs for adolescent orthodontic patients.

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