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Improving Toothbrushing with a Smartphone App: Results of a Randomized Controlled Trial

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Keywords

Toothbrushing · Oral hygiene · Children · Plaque index · Gingival index · Smartphone app

Abstract

Objectives: Performing proper toothbrushing is a complicated process for children. Therefore, the aim of this study was to investigate the effect of a smartphone app for improving manual toothbrushing via a gravitation sensor. ***Methods:*** In this prospective, controlled, single-blinded, randomized clinical trial, 49 children (mean age 5.1 ± 0.6 years, 27 female) were randomly assigned to test (n = 26) and control (n = 23) groups. All children were provided with manual toothbrushes with an integrated gravitation sensor and they received oral health instructions. Only the children of the test group got an additional smartphone app to visualize and reward proper brushing in form and time. At baseline and recalls after 6 and 12 weeks, plaque and gingival indices (QHI, PBI) were recorded for analysis between the two groups. ***Results:*** At baseline, there were no significant differences between the test and control group regarding plaque and gingival indices (QHI: 2.36 ± 0.7 and 2.42 ± 0.8; p = 0.94; PBI: 0.42 ± 0.2 and 0.47 ± 0.3; p = 0.59). At the 6- and 12-week recalls, the test group showed statistically significantly better oral health indices than the controls (6-week recall, QHI: 0.8 ±0.5 and 1.88 ± 0.9; p < 0.001; PBI: 0.08 ± 0.1 and 0.26 ± 0.2; p < 0.001; 12-week recall, QHI: 0.44 ± 0.5 and 1.49 ± 0.7; p < 0.001; PBI: 0.05 ± 0.18 and 0.21 ± 0.1; p < 0.001). ***Conclusion:*** The results highlight the enormous possibilities of a toothbrushing application via the smartphone, at least for medium-term oral hygiene improvement in preschool children and even after excluding the app. The long-term effect should also be investigated to exclude the expected novelty effect. © 2019 S. Karger AG, Basel

Introduction

Although caries is a preventable disease, it is still the most common chronic disease in children [World Health Organization, 2017]. In spite of the fact that about half of 6- to 7-year-old children in Germany are caries-free [TEAM DAJ, 2017], children in Germany are still far from the target of 80% caries-free 6-year-olds in 2020 [Oesterreich and Ziller, 2005]. One of the reasons for the relatively high caries prevalence in deciduous dentition is the early childhood caries [Gussy et al., 2006]. Therefore, starting suitable measures for good oral hygiene as early as possible is necessary for caries prevention [Splieth et al., 2016; Alm, 2008].

Several studies showed a positive association between good oral hygiene and low caries rates, and that adequate

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toothbrushing in children is considered to have a higher caries-preventive effect than diet and nutrition control [Vallejos-Sánchez et al., 2008; Tolvanen et al., 2010; Kaewkamnerdpong and Krisdapong, 2018]. The visible plaque on the tooth surfaces of infants and toddlers is a predictor for later caries development [Wendt, 1994]. In addition, the dental health in the primary dentition is an indicator of the subsequent dental health in permanent dentition [ter Pelkwijk et al., 1990; Li and Wang, 2002; Skeie et al., 2006].

Plaque control and toothbrushing behavior in school children is in need to be improved [Sandström et al., 2011; Pujar and Subbareddy, 2013]. Leal et al. [2002] found that plaque removal was more effective in children who had been instructed individually on the brushing technique [Creeth et al., 2009]. Pujar and Subbareddy [2013] reported more efficient plaque removal in 6-year-old children when longer duration of toothbrushing is preformed, so that a plaque reduction of 82% was achieved after 2.5 min.

For optimal toothbrushing, Kim et al. [2009] proposed a new approach for toothbrushing and patient's training using interactive training on toothbrush movements and applied a tilt angle. The advantage of this toothbrush navigation system was that the user can receive a clear and vivid picture of his/her current brushing result while brushing and can immediately correct the insufficient brushing.

Graetz et al. [2013] developed an interactive software to create a visual image for the brushing pattern of an individual in order to give recommendations for a better toothbrushing technique when needed. This optimized the brushing technique of the subjects, resulted in a long-lasting learning effect, and improved the oral hygiene.

A pilot study by Shapiro et al. [2008] showed that new technologies could play a role in improving the health of children in terms of exercise and nutritional behavior. This resulted in the DAYA system for efficient improvement of oral hygiene in children with a parental control option using transitional data. At the beginning, only 26% of children knew that poor oral hygiene was one of the risk factors for tooth decay, and 38% reported that they did not use any specific technique when brushing their teeth. With this mobile app, parents could track toothbrushing of their children [Shao et al., 2014].

The study "Children and Youth 3.0" showed that one fifth of 6- to 7-year-old children use smartphones [BITKOM, 2014]. There are numerous applications to support daily oral health for different age groups. However, so far, no study has examined the efficacy of these applications in improving individual oral hygiene. Therefore, the purpose of this study was to investigate the effectiveness of a motivational method using a manual toothbrush that is supplied with a gravity sensor and a mobile toothbrushing app in 5- to 6-year-old children.

Subjects and Methods

After approval by the ethics committee of the University of Greifswald (Reg. No. BB124/14), patients were recruited for this controlled, single-blinded randomized study with an observation period of 12 weeks. Out of total 66 invited children who were patients from a pediatric dentistry practice in Germany, parents of 60 children (27♂, 33♀) filled out the informed consent for the participation in this study. All children were willing to cooperate with the study's procedures. Inclusion criteria were 5- to 6-year-old children with an almost complete deciduous dentition and that children or their parents possess a smartphone with an iOS/Android operating system. Exclusion criteria were having severe general conditions, orthodontic appliances or motor restrictions. Due to the selected age range and the large number of teeth per child, the highest possible internal validity of the study could be guaranteed.

After giving informed consent, parents filled in a questionnaire of 6 questions about the medical history and 9 open questions about the current oral hygiene behavior of the children.

Children were enrolled randomly by a random list into test and control groups. For reliable blinding, the first practitioner individually gave the oral hygiene instructions, distributed the test toothbrushes and provided the manual instructions for the toothbrushes and the smartphone application. The second blinded practitioner carried out the examinations at baseline and at recalls after 6 and 12 weeks. This included oral hygiene indices: the papillary bleeding index (PBI) according to Mühlemann and Saxer [Saxer and Mühlemann, 1975] and the plaque index according to Quigley Hein (QHI) modified according to Turesky et al. [1970]. Furthermore, the adherence to oral hygiene instructions and toothbrushing technique have been checked at recalls.

The manual toothbrush Rainbow Vigilant™, which has a standard, flat bristle surface in an oval multitufted brushing plane (small size: 17 × 14 mm plane, 20 tufts in 4 rows, recommended for 5- to 6-year-olds) was given to each child. The toothbrush handle is made of colored anti-slip silicone and has a length of approx. 6.5 cm and a depth of approx. 2.2 cm. The handle is composed of a digital motion 3D sensor system (gyroscope), so that the toothbrush follows the toothbrushing movements of the child in real time. These movements are sent via Bluetooth to a smartphone (Android/iOS). Via Smart-Bluetooth and an iOS or Android smartphone, the application analyzes the toothbrushing movements. Using the motion sensors, the toothbrush detects the children's brushing habits and compares them in real time with the optimal movements via a mobile application. The summary of the learning progress is then displayed on the connected smartphone and can be shared immediately with family and friends. The app

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saves the data of each brushing session and adds bonus points in form of bears. The closer the child gets to the optimal brushing movements, the more points will be awarded. The mobile application has a main menu that gives access to the various sections, including step-by-step instructions. The application can be installed through a QR code.

The subjects of the test group (n = 30) received the necessary QR code and assistance with the installation and operation of the toothbrush application on a smartphone or tablet. The measured data of the gravitational sensor were transmitted via Bluetooth to the smartphone or the tablet of the parents.

The control group (n = 30) received no announcement of the QR code, and therefore the installation of the toothbrushing app in the control group was not possible. Accordingly, in the control group toothbrushing was only achieved with the same manual toothbrush as in the test group but without additional use of the motivational app.

The study included a total of 4 visits for each participant in the pediatric dental practice as shown in the flowchart of the study (Fig. 1).

Statistical Analyses

The sample size was calculated assuming a difference of 0.5 between groups at follow-ups, setting α = 5% and power $(1 - \beta)$ = 0.80 resulting in 26 children for every group. Adding an expected dropout of 15%, a total sample size of 30 in every group is needed.

The data analysis was performed with SPSS 14.0 for Windows (SPSS Inc., Chicago, IL, USA). There was evidence against the hypotheses that the data are normally distributed (p = 0.028 for time point 2; p = 0.014 for time point 3; Kolmogorov-Smirnov test); therefore and because of the small sample size of every group (smaller than 30), nonparametric tests were used. The Friedman test was used for intragroup analysis and Mann-Whitney U tests for analysis between the two groups. Still, mean values and standard deviation were given for clinical orientation of plaque and gingivitis scores.

The significance level was set at $p \leq 0.05$ for all statistical tests. Descriptive analyses were done for the questionnaire about previous oral hygiene of the subjects.

Results

Between December 2014 and February 2015, 60 children were recruited for the study. 49 participants (27 female) were included in the final statistical evaluation (mean age 5.1 ± 0.62 years, test group: n = 26). The reasons for dropout were: missing the examination appointments (n = 2), exclusion due to further tooth loss in the mixed dentition (n = 3), withdrawals due to the toothbrushing instructions and techniques being time-consuming (n = 2), due to the bulky toothbrush handle (n = 1), and no interest in the toothbrushing game (n = 3). There was no systematic bias in the test or in the control group.

Analysis of the Questionnaire

The majority of children (96%, n = 47) reported that they use fluoride toothpaste for the daily oral hygiene, whereas 2 children (4%) preferred toothpaste without fluoride. Previous to the study, about half of children (n = 27) used manual toothbrushes, while 34.7% (n = 17) used an electrical toothbrush and 10.2% of the subjects (n = 5) interchanged between electrical and manual toothbrushes.

40.8% of the participants reported that they replaced their toothbrushes every 4 weeks; 24.5% changed it every 2 months, and 24.5% every 3 months. 4.1% of the children did not report this information and the remaining 6.1% said they used their toothbrushes for more than 3 months. The frequency of the brushing was once a day in 1 participant (2.0%), 2 times in 39 subjects (79.6%), and 3 times in 9 subjects (18.4%).

About half of the children brush their teeth for 2 min, whereas the duration of toothbrushing was 1 min in 7 children (14.3%), and 3 min in 5 children (10.2%). Nine children (18.4%) spent more than 3 min brushing their teeth, and 3 participants (6.1%) did not report any information about the duration of toothbrushing. Toothbrushing duration was controlled in 40.8% of the children by an hourglass (18.4%), electric toothbrush timers (4.1%) or stopwatch (4.1%). 14.2% of children did not mention any time tracking tools. 19 children (38.8%) did not keep a precise time tracking, whereas in 8 children (16.3%) the time was occasionally checked. In 2 subjects (4.1%), the information for the toothbrushing duration was missing. Additional oral hygiene products such as dental floss and/or mouthwash have been used by 20 subjects (40.8%). Recall visits to the dentist for prevention were regular in only 10.2% of the children (n = 5).

Oral Hygiene with Toothbrushing App

In the test group, the brushing process and the collected reward points by the toothbrushing app were checked over a period of 6 weeks. The initial low scores between 3 and 15 points improved considerably within 10–14 days to over 30 points in the toothbrushing app users. All participants of the test group seemed to need at least a week of training to keep the number of bonus points stable afterwards. Most test subjects (87%) achieved the highest possible score of 36 after 2 weeks.

Initially mostly high mean values of the plaque index (QHI) were reported, which were almost identical for both groups (test group 2.36 ± 0.74; control group 2.42 ± 0.77,

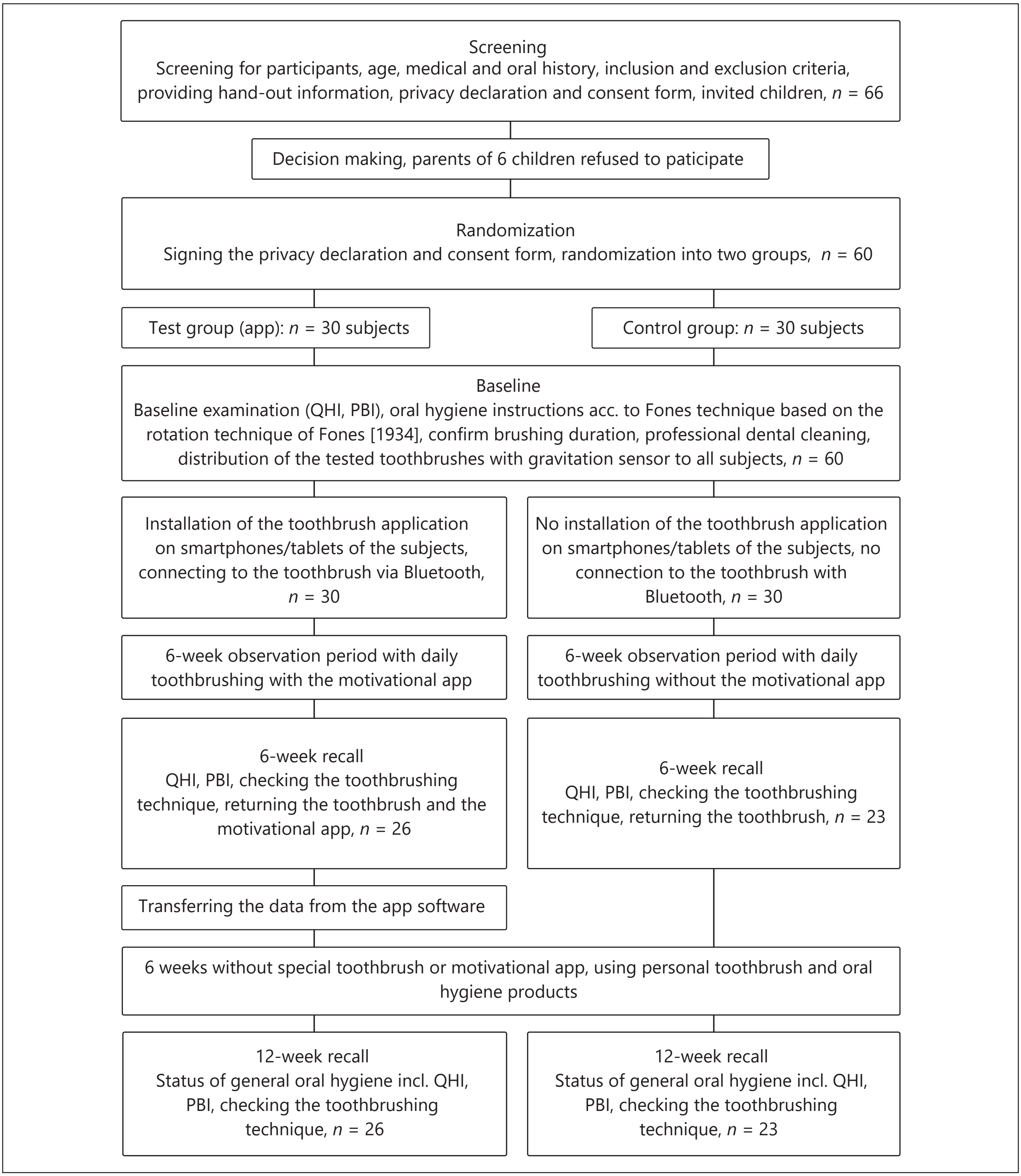

Fig. 1. Flowchart according to CONSORT for the study.

Table 1. Mean values for plaque indices at baseline and recalls after 6 and 12 weeks in the test and control groups

	Baseline (mean QHI ± SD)	6-week recall (mean QHI ± SD)	12-week recall (mean QHI ± SD)	Differences in mean ranks within every group
Test	2.36±0.74	0.58±0.48	0.44±0.48	χ^2 (2, n = 26) = 40.722 $p < 0.01$
Control	2.42±0.77	1.88±0.88	1.49±0.73	χ^2 (2, n = 23) = 27.573 $p < 0.01$
p value	0.94	<0.001	<0.001	

Table 2. Mean values for the papillary bleeding index (PBI) at baseline and recalls after 6 and 12 weeks in the test and control groups

	Baseline (mean PBI ± SD)	6-week recall (mean PBI ± SD)	12-week recall (mean PBI ± SD)	Differences in mean ranks within every group
Test	0.42±0.21	0.08±0.13	0.05±0.08	χ^2 (2, n = 26) = 35.512 $p < 0.01$
Control	0.47±0.28	0.26±0.00	0.21±0.14	χ^2 (2, n = 23) = 19.279 $p < 0.01$
p value	0.59	<0.001	<0.001	

$p = 0.94$). However, the subjects of both groups improved their plaque index scores, with a statistical significance in the test group at the 6-week recall (test group 0.58 ± 0.48, control group 1.88 ± 0.88, $p < 0.001$) as well as at the 12-week recall (test group 0.44 ± 0.48, control group 1.49 ± 0.73, $p < 0.001$, Table 1). Within every group, the improvements in the plaque index between baseline and recalls was statistically significant (test group: χ^2 (2, n = 26) = 40.722; $p < 0.01$, control group: χ^2 (2, n = 23) = 27.573; $p < 0.01$, Table 1).

At baseline, the PBI of the two groups was comparable (test group 0.42 ± 021, control group 0.47 ± 0.28, $p = 0.59$, Table 2). At the 6-week recall, the mean values of the PBI dropped in both groups. Still, in the test group, a much lower mean PBI was registered than in the control group (0.08 ± 0.13, 0.26 ± 0.00, respectively; $p < 0.001$). At the 12-week recall, the mean score of the PBI in both the test and control group increased marginally compared to the score of the 6-week recall, and the differences were also statistically significant. Within every group, the improvements in the bleeding index between the baseline and recalls were statistically significant (test group: χ^2 (2, n = 26) = 35.512; $p < 0.01$, control group: χ^2 (2, n = 23) = 19.279; $p < 0.01$, Table 2).

Discussion

In this randomized single-blinded trial, 60 children between 5 and 6 years of age were recruited at baseline and 49 subjects could be enrolled in the statistical evaluation after the study duration of 12 weeks. Dropouts were either neutral or to a lesser extent compliance-related, but this affected both groups. Thus, a dropout-related bias could be excluded for the comparison between the test and control groups. The number of participants had been selected according to published data [Wong et al., 2005; Pelka et al., 2011; Ganesh et al., 2012; Graetz et al., 2013; Shetty et al., 2013] to detect clinically relevant and statistically significant differences.

The follow-up duration of 12 weeks in the presented study is considered as a risk for the compliance of the subjects. The study duration in other studies on toothbrushing varied between 2 and 30 weeks [Ganesh et al., 2012; Graetz et al., 2013; Shetty et al., 2013]. The inclusion and exclusion criteria of this study were in line with similar studies [Leal et al., 2002; Ganesh et al., 2012], also resulting in an appropriate distribution of gender.

In order to create standardized conditions to investigate the effect of a smartphone app as a motivational tool for toothbrushing, all study participants received the same manual toothbrush. The installation and operation of the toothbrush application on the smartphone or tablet of the subjects was carried out in the test group only, while the control group did not have any access to the installations and, therefore, the application was not activated. This insured the adherence to the protocol during the study.

Regular mechanical plaque removal is a prerequisite for the control of periodontal diseases and carious lesions [Selwitz et al., 2007; Takahashi and Nyvad, 2008]. Therefore, the investigated variables of this study were the plaque index and the PBI.

In this study, there was a significant improvement in plaque removal on the smooth surfaces of the teeth in children aged 5–6 years in both study groups. However, a significantly greater reduction was observed for the test group compared to the control group. The clear improvement of the QHI values in the control group without the smartphone application can be explained with the Hawthorne effect in which people, who are the subjects of an experimental study, change or improve their behavior because it is being studied [Sedgwick and Greenwood, 2015]. Hence, the Hawthorne effect could have an influence on the internal validity of results. However, the clearly higher improvement levels achieved by the test group regardless of the Hawthorne effect indicate the notable effect of the intervention.

All subjects were instructed individually during the preparation phase about the toothbrushing technique on the toothbrush model. A better plaque removal can be achieved by video or by individual presentation on a model in comparison to written instructions [Leal et al., 2002]. The child-friendly design of the toothbrush might also have a motivating effect. In addition, each participant received a toothbrush in his favorite or desired color to encourage better compliance of children to the toothbrush. At baseline, there were no significant differences between study groups in the QHI or PBI. This confirms the integrity of randomization and recruiting conditions.

Both groups showed a decline in the mean plaque index over time, but this decline was more pronounced in the test group than in the control group, which gives evidence for the effectiveness of gaming in toothbrushing via a smartphone app. The toothbrushing application teaches children to follow the recommended brushing frequency and time, which are significant factors in achieving adequate plaque removal [Creeth et al., 2009; Pujar and Subbareddy, 2013] and finally also caries control [Kuusela et al., 1997; Chesters et al., 1992]. A recent study on adolescents with fixed orthodontic appliances by Scheerman et al. [2018] with similar primary outcomes and recall intervals to the presented study showed that offering personal oral health advice and automatic coaching via smartphone app is an effective means to reduce the plaque and bleeding indices significantly in comparison to the control group. The smartphone app used in the study by Scheerman et al. [2018] is based on the Health Action Process Approach theory, targeting changes in psychosocial factors such as outcome expectancies, intention, action self-efficacy, coping planning, and action control. These psychosocial factors may have a more significant effect on adolescents in the Scheerman cohort than on small or preschool children.

The sustained positive effect was reflected in the second recall after 12 weeks where the advantage of the toothbrushing app remained stable in the test group even after using the manual toothbrush for another 6 weeks without an activated app.

Throughout this clinical study, a significant improvement in the PBI could also be observed for both groups, but with statistically significantly better improvements in the test group, which can be attributed to the motivational effect of the smartphone app. The smaller improvement in the control may be in the Hawthorne effect and/or the child-friendly design of the toothbrush. A previous study referred to the role of the toothbrush design in improving the oral hygiene [Pelka et al., 2011].

Gingivitis can develop due to plaque accumulation in the cervical areas of the teeth in few days and it could be diminished after plaque removal [Löe et al., 1965]. Thus, it can be perceived as a secondary and robust parameter for oral hygiene. The development of the gingivitis scores follows and confirms the results of the plaque scores in this study.

The results from the baseline questionnaire about previous oral hygiene revealed mostly good results (96% fluoridated toothpaste, 79.6% brushing twice a day for about 2 min), which was in line with caries-preventive approaches of highest level of evidence [Walsh et al., 2010], but still the plaque and gingivitis scores could be improved considerably with the participation in the trial and especially by training with the smartphone app.

Conclusion

The present study highlights the enormous possibilities of a toothbrushing application via the smartphone, at least for medium-term oral hygiene improvement in preschool children and even after excluding the app. The long-term effect should also be investigated in a controlled study design to exclude the expected novelty effect.

Acknowledgement

We thank the children and their parents for participating in the study.

Statement of Ethics

This study has been approved by the ethics committee of the University of Greifswald (Reg. No. BB124/14). Parents of the involved children gave informed consent for the participation of their children in the study. All participating children have willingly cooperated with the study procedures.

Disclosure Statement

The authors have no conflicts of interest to declare.

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Author Contributions

M. Alkilzy contributed to the conception, design, and ethical approval, drafted and critically revised the manuscript; R. Midani drafted and critically revised the manuscript; M. Höfer contributed to the conception, design, data acquisition, analysis, and interpretation, and drafted the manuscript; C. Splieth contributed to the conception, design, and interpretation, and critically revised the manuscript. All authors gave final approval and agreed to be accountable for all aspects of the work.

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