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Evaluating Child Toothbrushing Behavior Changes Associated with a Mobile Game: A Single Arm Pre-Post Pilot Study

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Abstract

Purpose.—In this pilot study, we evaluated changes in toothbrushing behaviors associated with a mobile game.

Methods.—Children ages 5–6 years were taught to use the Brush Up game and played it once/day at home for seven days (N=34). The primary outcome was toothbrushing quality measured as duration and distribution. The paired t-test was used to assess pre/post changes and Holm's method adjusted for multiple testing (α=0.05).

Results.—The mean age was 73.7±6.6 months, 29.4% were female, and 47.1% were White. After seven days, toothbrushing duration increased significantly (P<0.001). Toothbrushing distribution improved with increased brushing of the lingual, maxillary occlusal, and posterior buccal surfaces. For children who played the game for 14 days (n=15), even greater improvements in quality and distribution were observed. Improvements in toothbrushing did not persist one year later without further app use but there were noted changes that could be clinically meaningful.

Conclusions.—Mobile health games can potentially improve toothbrushing quality in children. Additional trials are needed to assess mobile toothbrushing games.

Keywords

health app; children; toothbrushing behaviors; dental hygiene; technology; behavior change; mobile game; game application

Introduction

Tooth decay is a multifactorial disease that is preventable through regular toothbrushing.[1] Studies report 80% of children brush twice daily, but actual rates may be lower because of

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Author Disclosure Statement

GamesThatWork developed the Brush Up game and has an ongoing interest in its success. Two authors (JJ, DJ) are principals of GamesThatWork.

overreporting.[2–4] Many caregivers experience difficulties enforcing toothbrushing habits and an older study demonstrated children commonly miss tooth surfaces during toothbrushing.[5–7] These factors highlight the importance of developing strategies to improve toothbrushing in childhood.

Efforts to improve toothbrushing in children have focused on health education based on the premise that inadequate knowledge is the main barrier. However, findings from a recent systematic review indicate that health education alone does not significantly improve toothbrushing attitudes or behaviors.[8] Most caregivers know toothbrushing is important, but lack self-efficacy and other skills to enforce toothbrushing habits.[9]

Most families own devices that give them access to mobile health games.[10] Two systematic reviews reported limited support for mobile games,[11–12] but the original interventions were found to be passive (e.g., text reminders, monitoring), making it likely that the problem was with weak intervention design. In terms of toothbrushing games, a U.K. study surveyed 189 toothbrushing mobile game users ages 7–75 years (e.g., how clean did your teeth feel after using the game).[13] Most users were adults, the game was not tailored to children, and the study focused on perceptions rather than behaviors. A second study described a proposed intervention for a toothbrushing game for Dutch teens.[14] Dental researchers have explored online coaching, text messages, and “selfie” photographs as ways to improve toothbrushing, but none have been scaled commercially.[15–17]

Mobile toothbrushing games for children have become ubiquitous despite the lack of evidence demonstrating effectiveness. The goal of this pilot study was to evaluate a commercially-available mobile children’s toothbrushing game called Brush Up and assess whether the game could potentially help improve toothbrushing behaviors. We tested the hypothesis that game play would be associated with improvements in toothbrushing quality.

Methods

Game Development.

Brush Up is a theory-based mobile game that helps children develop toothbrushing skills through modeling, instructional song, and immediate performance feedback. The game teaches children the Modified Bass Stillman Technique. The game was originally developed using data from a series of formative evaluations with children ages 5–6 years at a Boys and Girls Club in Atlanta, GA. We focused on children ages 5–6 years because this is the developmental period in which many children begin to show signs of independence for health behaviors like toothbrushing and the minimal requisite motor skills, even though it is important to underscore the importance of adult supervision during brushing for young children. The game design includes an instructional song to guide brushing. Children helped refine the song’s words, voted on their favorite tune, and selected a cartoon exemplar. Subsequent formative tests showed that the initial exemplar selected by children (a dog) was difficult for children to emulate during toothbrushing. Instead, a “monster” with a child-like dentition and special jaw geometry was designed that would allow children to visualize the inside of the mouth while playing the game. The exemplar is gender, race, and ethnicity neutral to ensure appropriateness for children of all backgrounds (Figure 1).

Game Features.

Brush Up teaches the child to brush along with a song that lasts three minutes. The tempo sets the pace of sulcus strokes and sweeps. The rhythm counts off twelve miniscule strokes and three broad sweeps for each tooth surface before advancing to the next. The song and accompanying video progress through the mouth sequentially from tooth to tooth. An instrumented toothbrush monitors the child's performance while he or she brushes in tandem with a cartoon exemplar. The toothbrush incorporates an Inertial Measurement Unit (IMU), a package of gyroscopes and accelerometers. Data from sensors allow the software to continuously calculate the orientation of the toothbrush and infer its position in the mouth. The software directly reads the torque applied by sweeping motions, and can calculate brushing force as the child accelerates the brush back and forth. These data are reported in real time to the app using a Bluetooth Low Energy interface. The player is rewarded for accurate conformance with the demonstration. Performance errors are detected by the game system and immediately highlighted by verbal, visual, and sound effect cues in addition to a scoreboard penalty. The player is congratulated when these errors are later corrected.

Study Population.

Children ages 5–6 years were recruited from mixed-income neighborhoods in Atlanta, Georgia through posters placed in local stores, schools, and libraries in June and July 2012. There was also in-person recruitment of participants by a Research Assistant at local grocery store parking lots. The goal was to recruit a convenience sample of 34 children, which is what the limited study budget permitted. There were no a priori sample size calculations. Exclusion criteria were intellectual, developmental, or physical disabilities that might interfere with toothbrushing or gameplay. At the end of the study, each participating family received $200 as a thank you gift. The study was approved by the Morehouse School of Medicine IRB.

Study Procedures.

We obtained written consent from the child's primary caregiver and verbal assent from each child. Caregivers completed a survey on demographics (e.g., child's age in months, sex, race, ethnicity, grade, handedness). At baseline, all children brushed their teeth with a manual toothbrush in a GamesThatWork laboratory decorated as a bathroom with a sink and mirror. The child received no brushing guidance from any adult, peer, video, game, music, or clock. All toothbrushing visits were videotaped. Caregivers could observe through a small one-way window. Identical procedures took place during subsequent study visits.

After the baseline assessment, children were taught to use Brush Up by a Research Assistant. Each child was sent home with a sensor-enabled toothbrush and a laptop computer with Brush Up installed. The computer had Bluetooth connectivity to the toothbrush and Internet connectivity to the research servers, which enabled the team to record and monitor toothbrushing remotely. Caregivers were given instructions on how to set up the game at home, and were asked to have the child play each evening for seven consecutive nights (once/night). Caregivers were specifically asked not to provide any toothbrushing instruction during the study.

Outcome Measures.

The study was a pre-post intervention with a single arm. The primary outcome was toothbrushing quality measured as total time (in seconds) the child brushed and distribution of brushing, measured at baseline and at seven days after app use. Outcomes were based on video analysis performed retrospectively by a Research Assistant blinded to when the video was recorded. The video recordings measured total toothbrushing time. In addition, using electronic timers and video scoring software, a researcher assessed toothbrushing time on specific tooth surfaces to measure distribution of toothbrushing. The maxillary and mandibular arches were divided into an anterior zone with lingual and buccal brushing surfaces, and left and right posterior zones were divided into lingual, buccal and occlusal brushing surfaces (16 surfaces total) (Figure 2).

Data Management and Analyses.

Survey data were entered into a spreadsheet and verified for accuracy. Toothbrushing data were captured remotely and stored on secure servers. We generated descriptive statistics on the study population. Our main hypothesis was that toothbrushing quality would improve after seven days.

While developing the original study protocol, we wanted to evaluate outcomes again at 14 days for all children, but limited study resources permitted only a subset of families to participate beyond seven days. Accordingly, we conducted exploratory analyses to evaluate outcomes after seven additional days of app use (total of 14 days of app use) for first 15 children that enrolled in the study to test the exploratory hypothesis of whether there would be a dose response associated with additional game play. As part of a follow-up grant, we had the opportunity to compare outcomes at one-year post-baseline to assess if skills were sustained even though we acknowledge the high likelihood of insufficient statistical power. One-year comparisons were run separately for children who played the game for seven days (n=14) and 14 days (n=10). We used a 95% confidence interval and the paired t-test to evaluate pre/post changes (α=0.05). Holm's method was used to adjust for multiple testing. All analyses were conducted using SAS Version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Descriptive Statistics.

For the 34 children who were assessed after seven days of game play, the mean age was 73.7 months (standard deviation: 6.6 months), 29.4% were female, 47.1% were White, 5.9% were Hispanic, and 85.3% were right-handed. Demographics were similar for children assessed at 14 days and one year.

Main Hypotheses.

After seven days, there were significant improvements in the main outcome measure in which the mean total toothbrushing time increased by 23.1±31.5 seconds (95% confidence interval [CI]: 12.2, 34.1; P<0.001) (Table 1). Toothbrushing distribution improved, with significant increases on lingual, maxillary occlusal, and posterior buccal surfaces. The largest increase was observed for lingual surfaces from a baseline mean of 0.9 seconds to a

mean of 13.2 seconds (average increase=12.3 seconds; 95% CI: 7.4, 17.3). At baseline only 14.7% (5/34) of the children had any brushing of the lingual surfaces as compared to 76.5% (26/34) of the children who brushed lingual surfaces after seven days (McNemar's test; P<0.001).

Exploratory Hypotheses.

For the subset of children who played the game for an additional seven days (n=15 children), the mean total toothbrushing time increased by 69.0±51.2 seconds (95% CI: 40.7, 97.3; P<0.001) (Table 1). Toothbrushing time increased significantly on all surface types after 14 days. Similar to the seven-day results, the largest increase was observed for the lingual surfaces (average increase=35.1 seconds; 95% CI: 22.8, 47.3). At baseline only 26.7% (4/15) of the children had any brushing of the lingual surfaces as compared to 93.3% (14/15) after 14 days (McNemar's test; P=0.006).

The increases in time and changes in distribution observed after seven days and 14 days were not statistically significant after one year without game play(Table 2). However, there were improvements that failed to reach statistical significance but could be clinically meaningful. For example, in the group of children with 14 days of game play, as compared to baseline, the mean total time increased by 15.1 seconds (P=0.41) and the mean time for lingual surfaces increased by 9.5 seconds (P=0.18). At baseline only 20.0% (2/10) brushed the lingual surfaces compared to 60% (6/10) of the children after one year (McNemar's test; P=0.13).

Discussion

We assessed whether a toothbrushing app could improve toothbrushing quality in children ages 5–6 years. Our data show significant improvements in toothbrushing time and distribution for children who used Brush Up for seven days. Further improvements were observed for a subset of children who used Brush Up for 14 days. In the absence of continued app use, few improvements noted after seven and 14 days appeared to persist after one year. Collectively, these findings suggest that health apps are a promising strategy to improve toothbrushing behaviors in children, but that continual use may be needed to optimize improvements.

There are no published studies to which we can directly compare our findings. However, numerous studies from outside of dentistry have shown improvements in health behaviors associated with apps.[18–19] Total toothbrushing time increased by over 50% after seven days and nearly doubled after 14 days of app use (Table 1). These increases are clinically significant given that baseline toothbrushing time was high (46.2 and 39.9 seconds, respectively). Furthermore, there were significant improvements in toothbrushing of previously neglected tooth surfaces, including the lingual and maxillary occlusal surfaces, which are difficult areas to brush for young children.

Mechanism information on how apps like Brush Up improve toothbrushing behaviors is important knowledge that could be used for future app-based interventions. For instance, improvements in toothbrushing were greater for children who used the app for 14 days

compared to seven days. This suggests that longer app use may be associated with greater improvements, but the optimal intervention dose is unknown. A related issue is the length of the toothbrushing session. At the time of the study, the Brush Up song lasted three minutes. It may have been possible to achieve similar results with a two-minute song, a refinement that would reduce participant burden. In addition, the repetitiveness of health apps may lead to app fatigue over time. However, this is a positive feature for population subgroups for whom routines are important, including individuals with autism spectrum disorders.[6,20] Post-intervention interviews with families and child end-users could help to elucidate ways to optimize, refine, and tailor app-based interventions.

There were three main study limitations: 1) small sample size; 2) study was not a randomized clinical trial; and 3) no assessment of health outcomes. The small sample may explain why we failed to see statistically significant differences at one-year. Our study results are expected to inform sample size calculations for future interventions to ensure an adequately powered randomized clinical trial. Such a study would need to put in place strategies that would allow sufficient follow-up of participants to assess the extent to which longer-term behavior change is possible though app-based interventions. Participant incentives as well as e-incentives built into the app would help maintain participant engagement and follow-up. The third limitation could be overcome by including short- and long-term oral health outcomes assessments to assess whether toothbrushing with mobile games can prevent disease and improve oral health. It important to acknowledge the importance of adult supervision during toothbrushing, to ensure that an appropriate amount of fluoridated toothpaste is being used and to monitor appropriate brushing. We also recognize that caries is a multifactorial disease in which factors beyond toothbrushing such as minimizing added sugar intake and utilizing dental care are important in disease prevention.

In conclusion,

1. Toothbrushing games can potentially improve toothbrushing quality in children in terms of total brushing time and distribution.
2. Interventions need to be designed to achieve long-term, sustained improvements in toothbrushing and oral health.
3. Future research should continue to evaluate mobile games as part of intervention approaches to improve oral health behaviors and outcomes in vulnerable pediatric populations.

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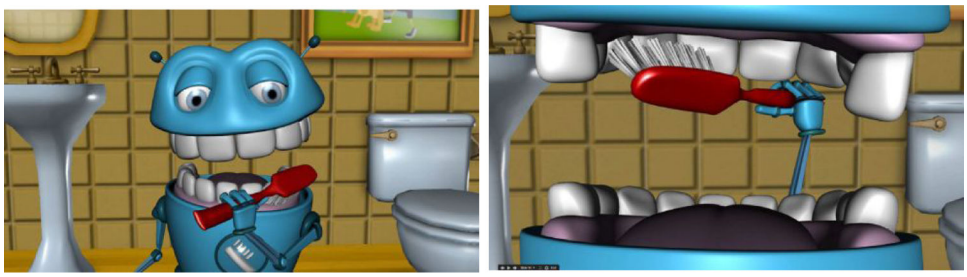

Figure 1.
Images of BrushUp cartoon exemplar and sample intraoral view of the cartoon's mouth that child sees while using BrushUp app

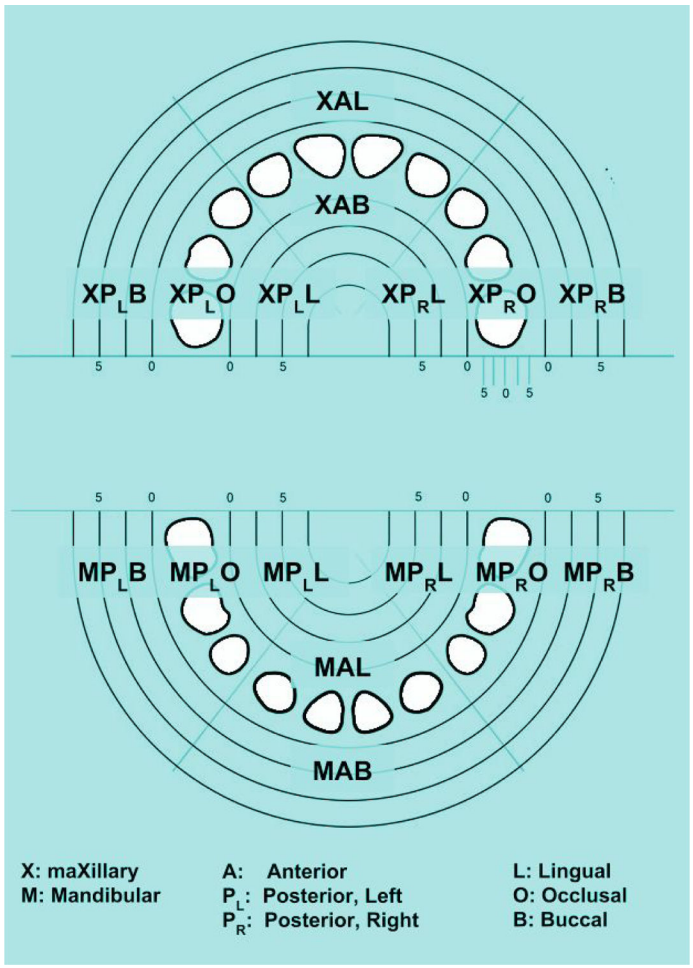

Figure 2.
Diagram indicating 16 segments of the mouth to assess distribution of toothbrushing

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Table 1

Toothbrushing Time (in Seconds) and Pre/Post Differences after Seven and Fourteen Days Post-Baseline

Tooth Surfaces	**Baseline n=34 Mean (SD)**	**After 7 Days n=34 Mean (SD)**	**Pre/Post Difference Mean (SD)**	**95% CI***	**P-value****
All surfaces	46.2 (31.3)	69.4 (30.4)	23.1 (31.5)	12.2, 34.1	0.0002†
Lingual surfaces	0.9 (2.3)	13.2 (14.1)	12.3 (14.2)	7.4, 17.3	<.0001†
Buccal surfaces	30.1 (28.6)	38.0 (21.7)	7.8 (21.9)	0.2, 15.4	0.045
Occlusal surfaces	15.2 (10)	18.2 (10.5)	3.0 (11.0)	−0.8, 6.8	0.12
Maxillary occlusal surfaces	5.9 (6.1)	9.2 (6.3)	3.3 (5.9)	1.2, 5.4	0.0028†
Mandibular occlusal surfaces	9.3 (6.7)	9.0 (5.6)	−0.3 (7.9)	−3.1, 2.5	0.83
Posterior buccal surfaces	15.7 (17.7)	22.8 (14.9)	7.1 (12.8)	2.6, 11.6	0.0027†
Anterior buccal surfaces	14.5 (14.3)	15.2 (10.2)	0.7 (12.5)	−3.7, 5.1	0.74
Tooth Surfaces	Baseline n=15 Mean (SD)	After 14 Days n=15 Mean (SD)	Pre/Post Difference Mean (SD)	95% CI *	P-value **
All surfaces	39.9 (21.0)	108.9 (47.6)	69.0 (51.2)	40.7, 97.3	0.0001†
Lingual surfaces	0.9 (1.6)	36.0 (22.3)	35.1 (22.1)	22.8, 47.3	<.0001†
Buccal surfaces	24.5 (18.3)	45.4 (18.0)	20.9 (18.0)	10.9, 30.8	0.0005†
Occlusal surfaces	14.4 (10.8)	27.5 (17.0)	13.1 (18.6)	2.7, 23.4	0.017†
Maxillary occlusal surfaces	6.5 (7.3)	13.1 (9.8)	6.7 (10.5)	0.8, 12.5	0.028
Mandibular occlusal surfaces	7.9 (5.6)	14.3 (7.9)	6.4 (10.0)	0.9, 11.9	0.026
Posterior buccal surfaces	13.5 (11.5)	28.4 (11.4)	14.9 (11.9)	8.3, 21.5	0.0003†
Anterior buccal surfaces	11.1 (9.2)	17.0 (7.6)	5.9 (7.6)	1.7, 10.1	0.0089†

*95% confidence interval for the average change between time points

**Paired t-test, p-value

†Statistically significant after adjustment for multiple testing, Holm's method (p-value < 0.05)

Table 2

Toothbrushing Time (in Seconds) and Pre/Post Differences One-Year after Baseline

Tooth Surfaces N=14 children who used app for 7 days	**Baseline Mean (SD)**	**After 7 Days Mean (SD)**	**After One Year Mean (SD)**	**Pre/Post Difference Mean (SD)**	**95% CI***	**P-value****
All surfaces	40.6 (23.8)	68.3 (34.9)	53.9 (47.4)	13.3 (54.2)	−18.0, 44.6	0.38
Lingual surfaces	0.4 (1.3)	13.5 (14.9)	0.9 (3.3)	0.5 (3.7)	−1.6, 2.7	0.60
Buccal surfaces	26.2 (27.4)	36.6 (24.3)	35.5 (34.8)	9.3 (45.6)	−17.0, 35.6	0.46
Occlusal surfaces	14.0 (8.9)	18.1 (11.7)	17.5 (15.5)	3.5 (12.8)	−3.9, 10.8	0.33
Maxillary occlusal surfaces	4.6 (5.0)	8.9 (6.6)	5.0 (5.8)	0.3 (5.2)	−2.7, 3.3	0.82
Mandibular occlusal surfaces	9.4 (7.6)	9.2 (7.2)	12.5 (13)	3.1 (13.7)	−4.8, 11.1	0.41
Posterior buccal surfaces	12.7 (18.8)	20.7 (17.5)	21.5 (24.8)	8.8 (28.2)	−7.5, 25.1	0.26
Anterior buccal surfaces	13.5 (14.0)	15.9 (12.0)	14 (18.6)	0.5 (26.9)	−15.0, 16.0	0.95
Tooth Surfaces N=10 children who used app for 14 days	Baseline Mean (SD)	After 14 Days Mean (SD)	After One Year Mean (SD)	Pre/Post Difference Mean (SD)	95% CI*	P-value**
All surfaces	45.7 (23.6)	119.1 (49.7)	60.8 (58.1)	15.1 (55.1)	−24.3, 54.6	0.41
Lingual surfaces	0.8 (1.7)	38.8 (23.8)	10.3 (20.2)	9.5 (20.5)	−5.2, 24.2	0.18
Buccal surfaces	28.8 (21.4)	49.8 (18.4)	37.7 (37.4)	8.9 (35.7)	−16.7, 34.4	0.45
Occlusal surfaces	16.1 (12.5)	30.5 (19.7)	12.9 (8.0)	-3.2 (16.8)	−15.2, 8.8	0.56
Maxillary occlusal surfaces	7.8 (8.6)	14.9 (11.1)	5.7 (5.1)	-2.1 (10.0)	−9.3, 5.0	0.52
Mandibular occlusal surfaces	8.3 (4.6)	15.6 (9.4)	7.2 (4.1)	-1.1 (7.7)	−6.6, 4.4	0.66
Posterior buccal surfaces	14.9 (13.9)	30.2 (12.1)	22.7 (20.5)	7.8 (18.5)	−5.5, 21.0	0.22
Anterior buccal surfaces	13.9 (10.2)	19.6 (7.5)	15.0 (21.6)	1.1 (22.1)	−14.7, 16.9	0.88

*95% confidence interval for the average change between pre-play and one year. See footnote A for exception.

**Paired t-test, p-value

†Statistically significant after adjustment for multiple testing, Holm's method (p-value < 0.05)