DAYA: A System for Monitoring and Enhancing Children’s Oral Hygiene

Abstract
Oral diseases are major public health problems that impact people from early childhood. However, children’s oral hygiene in China remains a severe problem due to inadequate education on oral hygiene behavior and parents’ lack of knowledge about their children’ dental condition. To address these problems, we propose DAYA, a system consisting of a toothbrushing game for children and a monitoring application for parents. The game is designed to enhance the efficacy and experience of tooth- brushing in children, and the application leverages data collected in toothbrushing to help parents monitor children's dental health and behavior.

Author Keywords
User-centered design; children; health care.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]: User Interfaces; J.3. [Health].

Introduction
Oral diseases are major public health problems that impact people from early childhood. As the most widespread infection among all the oral diseases, dental caries affects roughly 60-90% of school children in industrialized countries, impairing children’s quality of life and causing financial loss in the families [1]. The greatest impact of oral diseases is on developing
countries and socially marginalized populations. Children in families living below the poverty line have twice as many dental caries compared to more affluent peers in the U.S [2].

Despite the above, childhood dental caries and other early symptoms such as gingivitis can be controlled by adopting self-controlled healthy lifestyles, i.e. good oral hygiene habits [3]. Oral hygiene is proven to be an effective dental caries’ and gingivitis preventative measure for children [4]. Taking into account the severity of the problem, where many oral diseases are lifelong conditions [1] and the relatively low cost of maintaining oral hygiene habits (compared with dental services), it is essential for children to develop regular and effective tooth brushing habits. However, in China, 78% of 5-year-old children brush their teeth less than twice every day. One fifth of children do not brush their teeth daily. Among 12-year-old schoolchildren, 72% brush their teeth less than twice every day [5].

Another factor that may influence children’s oral hygiene comes from parents’ knowledge and attitudes toward children’s dental conditions [6]. Nine percent of parents with 5 year olds in China report that they review their children’s tooth-brushing daily. Meanwhile, forty-seven percent of 12-year-olds claim they’ve never seen a dentist [5]. When asked why, 87% of parents state that their children’s teeth appear fine or the problem is too minor to be treated. Thirteen percent believe that primary teeth can be left untreated [3].

For these reasons, it is essential to promote oral hygiene behavior changes among children and help fulfill awareness of children’s dental hygiene in parents [1]. Our research and design approaches help us identify user needs and design space: to collect data related to children’s oral hygiene and improve the efficacy and experience of children’s tooth-brushing.

**Approach**

We applied several methods to collect data about children’s and parents’ dental attitudes and behaviors to explore their deeper needs.

**Literature Review [7]** A literature review provided a theoretical understanding to the problems and risk factors of children’s dental health, which helped us identify important research and design factors.

**Drawing-Telling Technique [8]** We asked 32 children aged between 5 and 8 to freely draw their perspective about dental health. This method was applied so that younger children feel empowered with more time to organize their thoughts, and the possibilities of lying compared to verbal responses are reduced [9]. This process aimed to explore design opportunities based on the perspectives of children.

We found children feel confused about why they need to brush their teeth and some feel uncomfortable with it (fig. 1). Also children express fear of cavities and dental visits by drawing crying teeth. In addition, children express preference for candies although they are aware that candies cause dental problems.

**Interview [7]** Six parents and eight children were interviewed to collect data about their behaviors and attitudes towards oral health.

We found parents are very concerned about children’s dental health, which is demonstrated by the fact that many parents check their children’s teeth for dental caries by themselves and monitor their children’s oral hygiene activities. They have noticed deficiencies in their children’s way of tooth-brushing in terms of duration, frequency, techniques and area coverage.

**Fig 1.** An 8-year-old child’s drawing about tooth-brushing. Translation of the annotation: The tooth is brushed by his owner and is afraid. It wants to push the toothbrush away.
However, parents are restrained from sharing adequate hygiene education due to a lack of relevant knowledge. Parents are aware that their own ways of tooth-brushing differ from what is recommended by dentists, but they stick to it. Regardless, parents still hope that their children receive formal education on tooth-brushing.

Children, on the other hand, do not receive ample education on oral hygiene. Public school oral health education provides rather generic lessons such as “it is crucial to protect teeth” without explanations. Thus tooth-brushing is simply treated as a daily task instead of an essential or even playful activity.

These interviews provided evidence on parents’ concerns on children’s dental health and the lack of effective oral hygiene education children receive at home and in school.

**Observation** [7] To further understand children’s tooth-brushing habits, we observed 27 children aged from 5 to 12 brushing their teeth (15 at home, 12 at kindergarten). Children at home brushed as usual (fig. 2), while kindergarten children brushed under the guidance of their teachers.

In accordance with parents’ concerns and children’s attitudes towards oral hygiene, we observed a deficiency in the capability of tooth-brushing among young children. They are less likely to demonstrate general rules of brushing teeth, awareness of hard-to-brush oral regions, attention to time spent on each region, and an ability to brush vertically. This lack of proper techniques results in deficiencies in the area brushed and time spent on brushing. Minimal time was spent on brushing chewing surfaces on the upper right side. Few brushed the inner surface of teeth. Most children brushed below the recommended 2 minute range.

Another observation was that the instructions given by parents and kindergarten teachers were oftentimes misleading. A group of children from the kindergarten only brushed one particular region because they are instructed to. These observations revealed further problems of children’s oral hygiene behavior and its risk factors.

**Survey** [7] We conducted a survey amongst parents and collected 262 valid questionnaires. Among these parent participants, we surveyed 50 children to compare the findings.

The survey data supported interview results, showing 85% of parents were concerned about their children’s dental health. Parents are mainly concerned about these issues: insufficient brushing duration (74%), incorrect techniques (71%) and low repetition (20%). However, despite parents’ strong concerns about children’s dental health, a discrepancy is found between 50% of the parent and children pairs regarding children’s dental conditions. 10 out of 50 pairs showed a discrepancy in the numbers of children’s teeth affected by dental caries. Among them, 6 parents believe their children don’t have dental caries, while their children believe they do. This discrepancy suggests that parents need more accurate knowledge of children’s dental health and hygiene behavior.

Evidence also supported our observations on children’s oral hygiene education. Only 26% of the children know that infrequent tooth-brushing is a risk factor of dental caries and 38% reported they randomly brush their teeth without any proper technique. In addition, only 30% of students receive adequate oral health checks at school, which suggests more regular check-ups.
Solution
Through these researches, we found parents’ shared concern for their children’s dental health; however, due to limited knowledge on children’s dental health, parents fail to give better instructions. Meanwhile, children receive minimal education on oral hygiene and they treat tooth-brushing as a tedious task.

In conclusion to these findings, we decided to concentrate on parents’ need for monitoring and improving children’s dental hygiene habits as well as making tooth-brushing a more enjoyable process. Thus we present DAYA, a system that monitors and enhances children’s dental health and behavior. This system consists of a mobile application for parents, a tooth-brushing related game for children, and a toothbrush that tracks children’s tooth-brushing activity.

A Game to Improve Tooth-brushing Efficacy
Improving tooth-brushing behavior with games has been proven effective in previous researches. One research associated tooth-brushing with cleaning a virtual aquarium on a screen in place of a mirror, in which significant improvements in frequency and duration was reported [10].

The present design advocates further efforts by associating tooth-brushing behavior with a digital action-game displayed on a mirror. This game aims to enhance the tooth-brushing time and patterns of children, and collects data that will display on parents’ monitoring app. In the game, a child plays the role of a prince/princess defending a castle from invading monsters. Different brushing strokes engage different weapons to battle various monsters (fig. 3). Three aspects of tooth-brushing patterns are addressed in the game as they appear to be the most common and severe problems due to a lack of proper instructions from parents and teachers based on our observation together with the interviews and surveys with parents.

Coverage of Brushing Regions
Existing brushing sensor technology divides brushing regions into 16 parts (fig. 4) [11]. In the game, monsters come in from six routes associated with the sextants (fig 4). The monsters, which are blue, purple and orange, correspond with the three surfaces of teeth: the outer surface, the inner surface and the chewing surface. Children are required to brush the correspondent region to release bullets to the correct route (fig. 5).

Technique of Tooth-brushing
Monsters can only be attacked when the player brushes using a recommended gesture. The brushing gesture is identified by either a vertical or horizontal brush stroke, each of which is correspondent with a magic ball or a magic beam. This ensures monsters are attacked only if the brushing technique is correct.

Brushing Duration
The game is designed to last 2 minutes on the assumption the player kills off the monsters. If the player fails to kill the monsters, the monsters reappear, extending the game. If the child continues to brush incorrectly, parents will be notified.

Incentive Design
A ranking system, a mechanism of weapons and a badge achievement system are included in the game design for incentives.

Interactive Mirror Display
Recent mirror technology enables the augmented tooth-brushing experience to take place in a non-obtrusive manner. Based on our observation, most children’s tooth-brushing occurs in front of bathroom mirrors. In the game, when activities of the toothbrush are detected, the mirror will be activated and the game’s interface will appear. Thus
minimal attention and preparation when children are not brushing their teeth is required. Also interactive mirrors enable instant visual feedback which prompts children to change behavior. This technology has been experienced in laboratories [12] and in real life [13].

**Mobile App for Monitoring Children’s Oral Hygiene**
To address parents’ strong need for accurate knowledge about their children’s oral hygiene and dental behavior discovered in our research, three types of data are collected during the children’s tooth-brushing process: brushing duration and frequency, brushing regions and patterns, and oral bacteria.

In the dashboard, parents are able to review the scores and trends of their children’s tooth-brushing efficacy based upon three indicators: the average time spent on tooth-brushing, average area covered in tooth-brushing regions, and an overall grading of their children’s tooth-brushing patterns. Displayed beside these scores is the average performance of children in the same age group using the system and numbers recommended by dentists. Parents may also read a detailed analysis script for specific indicators, such as “Johnny spent only 2 seconds in brushing the inner surface of his upper-back teeth, and the recommended time is 10 seconds” to enable further improvement.

To obtain a deeper understanding of children’s oral hygiene and dental health, parents may also view a cartoon picture (fig 6.) of their children’s dental regions, which are colored green, yellow and red respectively based on the severity of their children’s problematic tooth-brushing. A quick tap on the region will give a more detailed description of the problematic tooth-brushing their children have (fig. 6).

By default, parents will receive notifications on four occasions: the child fails to brush their teeth on time; he or she fails to brush correctly; an increase is seen in the area of dental caries; and the brush head needs to be replaced. Parents are allowed to choose what and when they want to be notified in the settings.

**Feasibility of the Toothbrush**
Toothbrushes that are able to record brushing duration and frequency are already available in the market. Data is logged with three-axis accelerometers linked to a built-in memory and data can be transferred through Bluetooth to a smartphone application [14].

Previous researches have successfully identified tooth-brushing regions and patterns using three-axis accelerometers and magnetic sensors that are implanted inside toothbrushes. Tooth-brushing regions are divided into sixteen parts in the present game design, which is in accordance with the regions identified in previous researches [11].

The toothbrush utilizes the fluorescence effect of porphyrins, the metabolites of oral bacteria that cause dental caries, which fluoresce when red light is activated to detect the early onset of dental caries. Once an excessive amount of porphyrin is detected, an alert is shown on the parents’ monitoring app. This technology is already available in clinical practice [15].

**Process and Evaluation**
**Iteration** Alternatives were first sketched and low-fidelity prototypes of the game were designed and printed for usability testing. Medium-fidelity prototypes were then built based on testing results. Medium-fidelity prototypes of the mobile application evolved from a few sketches that were first made to explore
design possibilities. We went through 2 iterations after internal heuristic evaluation and tests with users.

**Usability Testing of The Game** We conducted usability tests on low-fidelity prototypes of the tooth-brushing game with 16 children (aged 6 to 10) using Wizard of Oz (fig. 7) [8]. The tests were carried out either individually or collaboratively under personal contexts (kindergartens, schools, or homes). All the children showed great enthusiasm for playing the game. 15 out of 16 children indicated that this game made tooth-brushing more enjoyable.

We found that older children aged from 8 to 10 understood the game better and made fewer mistakes than those aged from 6 to 7. Thus we decided to adjust the difficulty of the game according to children’s age.

**Usability Testing of the Mobile Application** We conducted usability tests on the monitoring app with 5 parents after internal heuristic evaluation. All the users succeeded in completing the following tasks on an interactive version of the mid-fi prototype: creating a child profile, reviewing the dashboard and details, and customizing the settings. Refinements on icons and wordings were made based on the users’ feedback.

**References**


