Modulating tooth brushing sounds to affect user impressions

Taku Hachisu

The University of Electro-Communications / JSPS Research Fellow,
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585 Japan
E-mail: hachisu@kaji-lab.jp

Hiroyuki Kajimoto

The University of Electro-Communications /
Japan Science and Technology Agency,
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585 Japan
E-mail: kajimoto@kaji-lab.jp

Abstract: We present a novel feedback technique for tooth brushing. Brushing sounds were manipulated and were found to alter the user's impression. In our experiment, brushing sounds recorded by a microphone in the toothbrush are manipulated and presented to the users in real-time. We demonstrate that frequency manipulation affects feelings of comfort and accomplishment when sound levels are amplified. We also show that the gradually increasing frequency of brushing sounds induces more comfortable and accomplished feelings than the original sounds. The results show that it is possible to motivate users by interactively manipulating the frequency of brushing sounds.

Keywords: audio filter; augmented reality; band pass filter; brushing sound; feeling of accomplishment; feeling of comfortable; parchment-skin illusion; perception interaction effects; sound effect; sound feedback; sound manipulation; toothbrush.

Reference to this paper should be as follows: Hachisu, T. and Kajimoto, H. (yyyy) 'Modulating tooth brushing sounds to affect user impressions', *int. J. Arts and Technology*, Vol. x, No. x, pp. xxx-xxx.

Biographical notes: Taku Hachisu is a Ph.D. candidate at the Department of Informatics at the University of Electro-Communications, Japan. He is a research fellow of Japan Science Promotion Society. His research interests are haptic augmented/virtual reality, and multimodal human-computer interactions.

Hiroyuki Kajimoto received a PhD in information science and technology from the University of Tokyo in 2006. He is currently an associate professor in the Department of Informatics at the University of Electro-Communications, Japan. His research interests are tactile displays, human interface, and virtual reality.

Introduction

Tooth brushing is an important daily habit for oral hygiene. It maintains oral cleanliness and prevents caries and periodontal diseases. For these purposes, tooth brushing must be done frequently and correctly. However, brushing is often not carried out correctly or may simply be forgotten because the task is considered boring. Here, we address two major issues regarding why people do not complete tooth brushing.

One reason is a lack of motivation. It is considered as a simple task where users do not feel a sense of accomplishment. Tooth brushing provides a “negative reward” for users as they brush their teeth to avoid developing caries. Subsequently, users do not consider the impact of omitting the action until suffering from caries or other dental diseases.

The other issue concerns incorrect brushing technique, such as insufficient brushing time and applying too much pressure to the teeth. Incorrect brushing techniques are not only ineffective, but also create a risk of adverse effects. For example, applying too much pressure to the teeth damages the gum-ridge. However, it is difficult to inform people (especially children) on how to correctly brush their teeth.

In this paper, we present a novel feedback system that alters user impressions of the tooth brushing experience by using perception interaction effects. We find that modulating the brushing sounds can affect user impressions in terms of feelings of comfort and accomplishment. We believe that these impressions should generate feeling of motivation or may be used to teach correct brushing technique by providing positive or negative impressions associated with correct or incorrect brushing.

This paper begins with a review of previous approaches and concepts for improving current tooth brushing that considers intuitive feedback. The paper then describes a literature review of perception interaction effects on oral cavity. We then describe the details of our proposal and demonstrate its efficacy through two experiments. The paper concludes with a discussion of the experimental results.

Related work

Previous Work on Toothbrushes

As mentioned previously, one of the reasons as to why tooth brushing is often neglected is from a lack of motivation due to the negative reward. By encouraging a positive reward, the user should be more highly motivated. Nakajima *et al.* (2007) established a virtual aquarium where tropical fish displayed on a liquid crystal display (LCD) become active and produced eggs if the user brushes their teeth. An accelerometer in the toothbrush measures the activity. Arm & Hammer Spinbrush (2012) released Tooth Tunes, which consists of a small pressure sensor that detects contact between the bristles and the teeth. A bone conduction speaker plays a music clip upon contact. These methods motivate users by providing alternative rewards through elements of entertainment.

To deal with the issue of incorrect brushing technique, the Professional Care SmartSeries 5000 with SmartGuide Electric Toothbrush has been released by Oral-B (2009). This divides the teeth into four sections and counts the brushing action on an LCD to show how many times the users have brushed their teeth and how long they should continue to brush them. Chang *et al.* (2008) developed the Playful Toothbrush, which encourages children to brush their teeth correctly by tracking the toothbrush and identifying where they are brushing. The Playful Toothbrush has a visual and auditory feedback reward, such as beautiful animations and sounds that occur in accordance with correct brushing performance, thus motivating children to brush their teeth.

These works provide sufficient motivation and improve the way people brush their teeth. However, feedback quality is an issue. Although the previous works presented cues with visual displays or music to guide correct tooth brushing, the feedback is remote from the brushing itself. The feedback is not intuitive and users must learn what the cues mean. An approach is required that provides intuitive cues for correct tooth brushing that will also motivate users.

The purpose of this paper is to develop a novel feedback method that makes tooth brushing entertaining in an intuitive way. To achieve this goal, we established two methods. To avoid presenting information on a visual display, we modulated ordinary tooth brushing impressions by haptic and auditory sensations. We believe that modulation of these sensations is the simplest, and also a robust way of presenting information intuitively. We also aim to interactively design the modulations so that the user vividly feels that their teeth are becoming cleaner, thereby providing motivation.

Sensory Presentation in Oral Cavity

A number of works studying sensory perception in the oral cavity were carried out to simulate or enhance the eating experience. Because the tooth brushing experience focuses on tactile and auditory sensations, we look at previous works related to these two sensory perceptions in the oral cavity. Although taste and olfactory sensations are also involved during tooth brushing, they are not considered in this paper. These sensations are difficult to control in terms of temporal resolution, making them unsuitable for our second concept.

Presenting Haptic Sensation

Iwata *et al.* (2004) developed the Food Simulator, which is a haptic interface that generates a force on the users' teeth that simulate food texture by means of a one degree-of-freedom (DoF) mechanism. They successfully presented food texture and chemical taste. However, applying a force feedback mechanism to a toothbrush is impractical as a multiple DoF force feedback device is required, requiring high costs.

Hashimoto *et al.* (2008) established the Straw-like User Interface (SUI), which is an audio-tactile interface that presents vibrations and sounds resulting from suction with a straw. They demonstrated that the SUI simulates the experience of drinking. However, tooth brushing produces vibrations and sounds that mask additional vibrations. This makes it difficult to directly modulate the haptic experience of tooth brushing.

Presenting Auditory Sensation

Zampini and Spence (2005) found that potato chips are perceived as crisper and fresher when overall sound levels are raised or when the frequency of the biting sound is amplified. Koizumi *et al*. (2011) employed this effect to augment the experience of biting and chewing foods by synchronizing jaw action.

These techniques can be used to modulate sensations in the oral cavity and can easily be realized by using auditory interfaces, such as a microphones and headphones, without complicated mechanisms like haptic interfaces. These techniques are practical.

In the field of cross-modal research, haptic perceptions of a variety of surface textures (including outside the oral cavity) can be altered by modulating auditory cues (Guest *et al.*, 2002; Jousmäki and Hari, 1998; Lederman *et al*., 2002). Jousmäki and Hari (1998) demonstrated that sounds that are exactly synchronous with the sound of hand-rubbing modifies the resulting tactile sensation (the parchment-skin illusion). The palm is perceived as being smoother and dryer, like the surface of paper, when the high-frequency component of the rubbing sound is amplified, or when the overall sound level is increased. We expect that this cross-modal phenomenon enhances the modulation effect.

Zampini *et al.* (2003) studied the modulation effects of an electric toothbrush. In their experiment, participants brushed their teeth with the electric toothbrush with manipulated sounds. They then rated either the pleasure or the roughness of the vibrotactile stimulation from the electric toothbrush. The results show that tooth brushing is more pleasant and less rough when the overall sound level is reduced, or when the high-frequency sounds were attenuated.

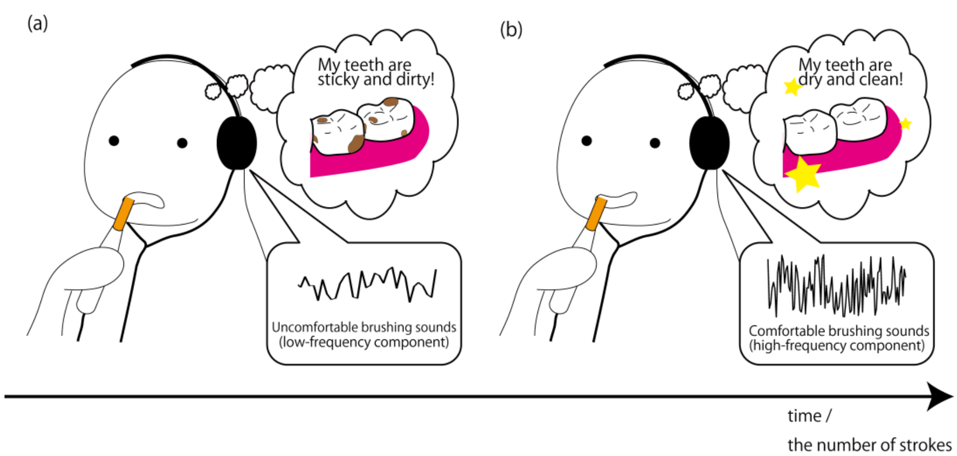
These results seem to contradict those from Jousmäki and Hari (1998) in terms of smooth-rough relationships with frequency. This probably results from a major sound source, such as that produced by the motor or motion of the user. Regardless, the study demonstrates that modulating the frequency of brushing sounds does affect user tooth brushing experience.

Approach

From previous work on sound manipulation, we suppose that these techniques can be applied to a toothbrush by embedding a microphone in the toothbrush and presenting filtered brushing sounds (e.g., band pass filter).

In this paper, we focus on sounds resulting from manual tooth brushing. Manual brushing is still more common than using electric toothbrushes. Especially in regard to the public health of developing countries, this has a larger impact. Jousmäki and Hari's work (1998) refers to sounds produced by user's motion, where amplifying the low-frequency component evokes a moist (or sticky) and rough feeling on the teeth (Figure 1-a). This makes the users feel uncomfortable. In contrast, amplifying the high-frequency component of the brushing sounds evokes a dry and smooth feeling, making the users feel more comfortable (Figure 1-b).

Figure 1 (a) The low-frequency component of brushing sounds evokes an uncomfortable sticky and rough feeling on the teeth, (b) the high-frequency component evokes comfortable dry and smooth feelings.



We expect that it is possible to achieve our first objective to intuitively modulate the brushing experience by controlling the comfort level and allowing users to be aware of the condition of their teeth. Our second objective is also possible. Enhancing feelings of accomplishment by interactively designing sound manipulation can provide motivation. For example, controlling the impression from "dirty" to "clean" associated with brushing time enables users to vividly understand the cleaning progress, thereby motivating them to complete the game.

By associating these techniques with a toothbrush tracking sensor, such as that presented by Chang *et al.* (2008), it is possible to present the condition of each tooth. The system counts the number of strokes on each tooth (Figure 2-a) and manipulates the sound to evoke either a comfortable or uncomfortable feeling based on the count. The peak frequency of the band pass filter increases as the count increases (Figure 2-b). For example, if a tooth has been brushed well, the system provides a comfortable brushing (high-frequency) sound (at Surface2 and Surface4 in Figure 2). If the brushing is insufficient, it provides an uncomfortable (low-frequency) sound (at Surface1 and Surface3 in Figure 2). This enables users to know which of their teeth have been brushed enough and which have not. The user can intuitively and immediately know how many times and which teeth they should brush further.

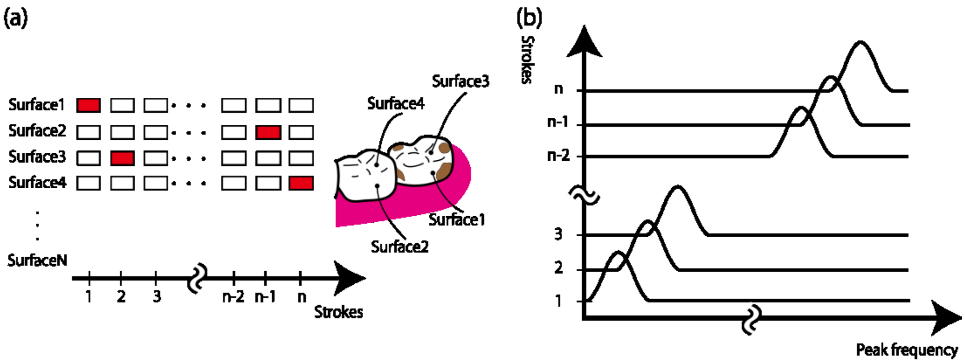
Experiment

Two experiments were conducted to determine if our approach is capable of modulating the user's impression. In Experiment 1, we examined how the manipulated brushing sounds affect users' impression. In Experiment 2, we examined the effects of sequentially filtering certain brushing sound characteristics on user impressions of the experience.

Experiment 1: Does manipulating the brushing sounds affect user impressions?

To investigate if manipulating brushing sounds can affect user impressions of tooth brushing, we conducted an experiment in which participants were asked to evaluate their feelings of comfort and accomplishment from brushing. The former feeling is mainly

Figure 2 The toothbrush tracking system: (a) the system counts the number of strokes on each tooth, and (b) the peak frequency of the band pass filter is determined based on the stroke count.



relevant for creating intuitive cues, while the latter relates to how the design motivates users.

Setup

Toothbrush. We created a toothbrush (Figure 3) with an interchangeable brush (Asia Networks Co., Ltd., Tokyo, Japan). The toothbrush has a length of 160 mm, with a weight of 20 g. Figure 3-c shows the internal configuration of the handle, which was made of acrylonitrile butadiene styrene (ABS) resin and contains a microphone (capacitor microphone, WM-61A, Panasonic Co., Tokyo, Japan) to record brushing sounds, and a force sensor (miniature load cell, LMA-A-5N, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) to measure grip force. The microphone was attached to a central core, which connects to the brush, allowing the brushing sounds to be directly recorded. The force sensor is fixed beneath the bump in the handle.

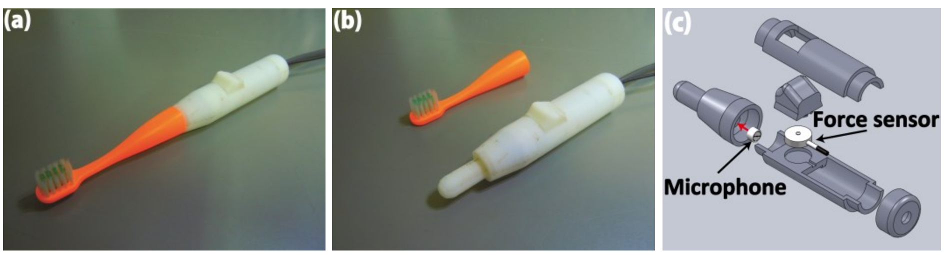
Recorded sounds were sent to the microphone jack of a computer. The signal of the force sensor was also sent to the computer via a microcontroller (Arduino Duemilanove, Italy). These two signals were processed to provide auditory cues as described in the following section.

Sound processing. A Max (version 6.0, Cycling '74, Walnut, CA, USA) was used as the sound processer. To feedback the brushing sound, we used a band pass filter. This was used in preliminary investigations and seemed to be the best filter to modulate impressions in which we compared a high pass, low pass and band pass filter. We prepared five peak frequency conditions (500-, 1000-, 2000-, 4000-, and 8000-Hz) with a constant Q value (1.0). We also prepared an unfiltered condition as a control condition.

As indicated in previous work (Guest *et al.*, 2002; Jousmäki and Hari, 1998; Zampini *et al.*, 2003; Zampini and Spence, 2005), the overall sound level affects perception. We investigated three sound level conditions (-20, 0 and +20). The default sound level was set at approximately 75 dB (A) using a sound level meter (digital sound level meter, TM-102, Sato Shouji Inc., Japan). For the other two conditions (-20 and +20), the sound levels were set by the Max.

In preliminary investigations, we found that the amount of force applied to the toothbrush influenced feelings of comfort and accomplishment from brushing. To avoid this, a beeping sound (1000-Hz sinusoidal wave) was emitted if the grip force exceeded 20 N.

Figure 3 Toothbrush used in Experiment 1. (a) and (b) show a toothbrush with an interchangeable brush. (c) shows internal configuration of the toothbrush handle containing a microphone and force sensor.



Environment. As shown in Figure 4, the participants sat on a chair in front of a table and next to a sink, with headphones (sound-isolating earbud headphones, EX-29, Direct Sound Headphones Inc.) on their head. The toothbrush, an LCD, a ten-key keypad, a cup of water, and potato chips were placed on the table.

Procedure

The participants were instructed how to brush their teeth. They gripped the toothbrush in their right hand in a similar way as holding a pen, with their thumbs on the bump of the handle (the force sensor). They were instructed not to grip too tightly to avoid the beeping sound. They were asked to brush the buccal surface of the left upper second and third molars using five strokes and employing the Bass method (Bass, 1954).

In each trial, the participants first brushed their teeth under the standard condition (unfiltered sound at 0 dB). Next, they brushed their teeth under a comparative condition. They then rated their feelings of comfort and accomplishment by moving markers on the analogue scale bars on the LCD using the keypad. The left end (0) of the feeling of comfort / accomplishment scale bar represented “uncomfortable” / “not brushed at all”, while the opposite side (100) represented “comfortable” / “brushed well”. The participants were asked to rate each of these two scales when the standard condition was rated 50. No time limit was imposed for the answer.

Each participant performed this evaluation 54 times; (five peak frequency conditions

Figure 4 Setup for the experiments.

+ one non-filter condition) × three sound gain conditions × three repetitions. Comparative conditions were randomly presented and the participants were unaware of the parameters.

Before the trials, the participants practiced this procedure several times without headphones. After every nine trials, they ate a piece of potato chip, chewing them on the left side to keep their teeth dirty. They were allowed to rinse their mouths freely during the experiment. After the trials, we asked the participants an open question.

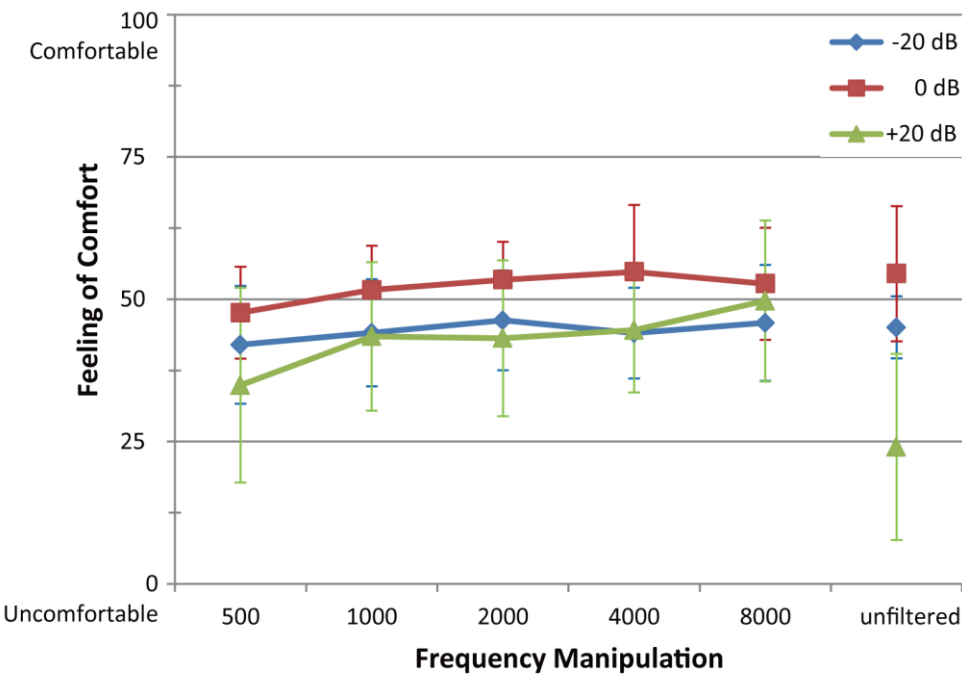
Seven participants—four men and three women—aged between 22 and 25 (mean =22.9; SD = 1.2) took part in the experiment. All participants were right-handed.

Results

Feelings of comfort. The results of the analysis of feelings of comfort for the three different sound gain conditions with respect to the six frequency manipulation conditions are shown in Figure 5. A two-way within-participants repeated measure analysis of variance (ANOVA) was performed on the data. The within-participants factors were Frequency Manipulation (i.e., peak frequency; 500, 1000, 2000, 4000, and 8000 Hz and the control condition) and Sound Gain (i.e., -20, 0, and +20 dB).

The main effect of Sound Gain was significant ($F(2, 12) = 4.51$; $p < .05$). The interaction effect between the Frequency Manipulation and Sound Gain was significant ($F(10, 60) = 3.10$; $p < 0.01$). Simple main effects were found for Sound Gain under 4000 Hz ($F(2, 12) = 4.69$; $p < 0.05$) and unfiltered conditions ($F(2, 12) = 7.68$; $p < 0.01$), and for Frequency Manipulation at the +20 dB level ($F(5, 30) = 4.69$; $p < .01$). This implies that the Frequency Manipulation has a greater influence on comfort at +20 dB than at the other Sound Gain levels of -20 or 0 dB.

Figure 5 Mean values of the feeling of comfort for the three sound gain levels with respect to the six frequency manipulation conditions. Error bars denote standard deviation.

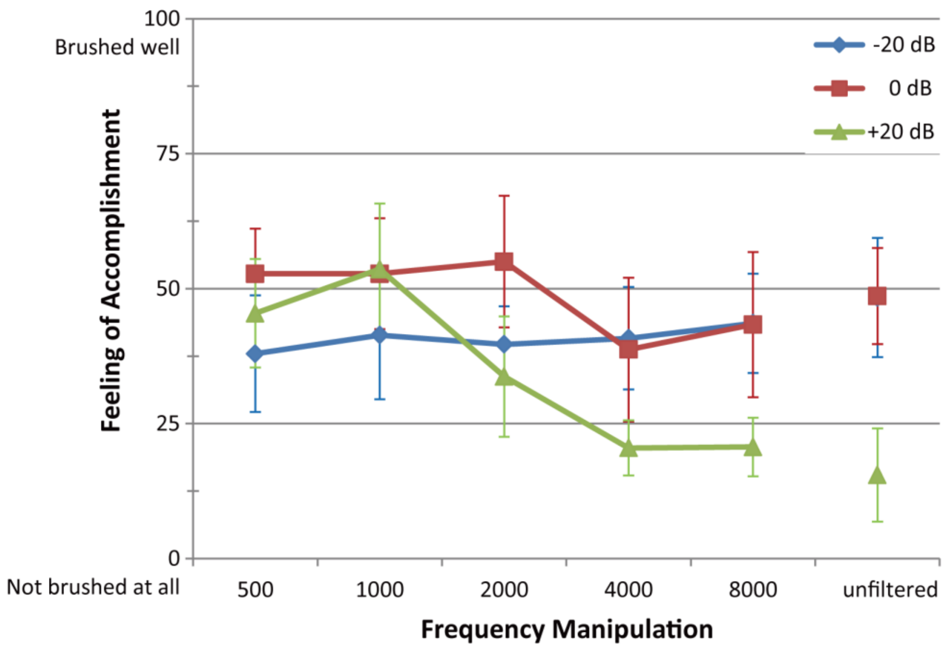


Feeling of accomplishment. The results for the feelings of accomplishment for the three sound gain levels with respect to the six frequency manipulation conditions are shown in Figure 6. An ANOVA was performed on this data similar as that for the feeling of comfort data.

The main effects of Frequency Manipulation ($F(5, 30) = 13.12$; $p < 0.01$) and Sound Gain ($F(2, 12) = 21.33$; $p < 0.01$) were significant. The interaction effect between Frequency Manipulation and Sound Gain was also significant ($F(10, 60) = 6.22$; $p < 0.01$). Simple main effects were found for Sound Gain under 2000 Hz ($F(2, 12) = 5.12$, $p < 0.05$), 4000 Hz ($F(2, 12) = 9.11$, $p < 0.01$), 8000 Hz ($F(2, 12) = 18.33$, $p < 0.01$), and the unfiltered conditions ($F(2, 12) = 29.07$, $p < 0.01$), and for the Frequency Manipulation under the +20 dB level ($F(5, 30) =25.12$, $p < 0.01$). This implies that the effects of Frequency Manipulation had a greater influence on the feeling of accomplishment than for the other Sound Gain levels, similar to the feeling of comfort.

Correlation between the feelings. The mean scores were plotted on a two dimensional graph to investigate the correlation between the two scales as shown in Figure 7. The x- and y-axes denotes feelings of comfort and accomplishment, respectively. Spearman's rank correlation coefficiency test performed on the data showed a weak positive correlation ($r = 0.3583$) between the scales, however, it was not significant ($t(16) = 1.54$; $p = 0.14$).

Figure 6 Mean values for the feelings of accomplishment feeling for the three sound gain levels with respect to the six frequency manipulation conditions. Error bars denote standard deviation.



We also performed Spearman's rank correlation coefficiency test on the data obtained at +20 dB under frequency manipulation (i.e., 500, 1000, 2000, 4000 and 8000 Hz). The frequency manipulation had significant influence on the evaluation. We found a stronger, but negative correlation (r = -0.6) between the scales. While we found no significant correlation ($t(3) = 1.30$; $p = 0.28$), the negative correlation implies that a comfortable

Figure 7 Correlation between feelings of comfort and accomplishment.

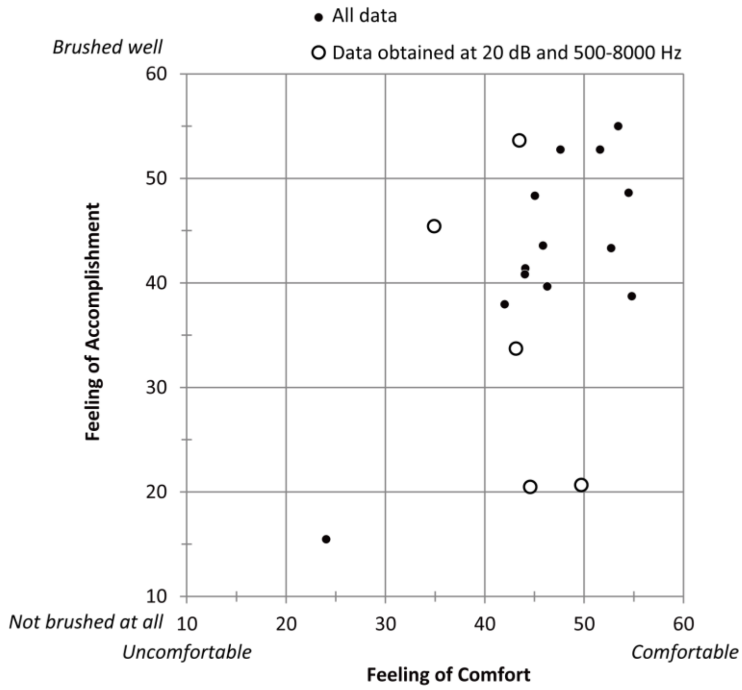


Table 1 Comments from participants answering the open question asked after Experiment 1.

Comments	No.	Comments	No.
Louder sounds provide feelings of accomplishment.	4/7	High-frequency sounds made teeth feel dry.	1/7
Excessively loud sounds were uncomfortable.	2/7	High-frequency sounds were comfortable.	1/7
Excessively sounds did not provide feelings of accomplishment.	1/7	Low-frequency sounds made teeth feel sticky.	1/7
Softer sounds were uncomfortable.	3/7	Environmental sounds captured by the microphone were uncomfortable.	2/7
Softer sounds did not provide feelings of accomplishment.	2/7		

feeling does not always induce feelings of accomplishment or vice versa, despite our expectations. The results also indicate that participants distinguished and rated the two scales.

Open question. Table 1 shows the major comments from participants regarding an open question asked after the experiment. Although these data are qualitative, the major tendencies from the sensation participants felt were similar to those found by Jousmäki and Hari (1998). Main responses indicated that the high-frequency sounds induce a dry sensation and low frequency sounds induce sticky sensations.

However, these tendencies conflict with the results of Zampini *et al.* (2003). We found that high-frequency sounds felt comfortable while Zampini *et al.* found that attenuated high-frequency sounds were more pleasant. The supposed reasons for the difference may be influenced by the following points. The major sound source in their work used electric toothbrushes, which produced continuous motor sounds. The frequency bandwidth of the audio filter for Zampini *et al.*'s work used 2-20 kHz filter, which was much higher than our filters of 500 Hz - 8 kHz.

Discussion

The results demonstrated that increasing the sound gain and manipulating the frequency can influence feelings of comfort and accomplishment. It is possible to provide intuitive cues using feelings of comfort and to provide motivation by controlling the feelings of accomplishment.

After the experiment, one participant commented that the brushing sounds that were too loud evoked feelings of insufficiency, as they felt as if they had not brushed their teeth by themselves. This probably explains why feelings of accomplishment were rated low at +20 dB conditions. Participants reported that some conditions were so loud that they felt uncomfortable, which probably explains the low comfort ratings at +20 dB conditions. Based on comments that the +20 dB condition was too loud for some participants, we suppose that there is a better amplification level between 0 dB and +20 dB.

However, at the +20 dB level, frequency manipulation had a greater influence on both feelings as shown by the simple main effect. Participants felt comfortable when the higher band pass filter was applied. Participant felt insufficient when the higher band pass filter was applied, which seemed to peak at around 1000 Hz.

At the -20 dB and 0 dB levels, however, frequency manipulation did not influence either feeling. One of the possible reasons for this is that at the -20 dB level, the sound was so soft that participants could not perceive the change in frequency. Even at the 0 dB level, the sound gain might not have been enough to perceive the change as applying the band pass filter further decreased the overall sound level.

Although there were no significant correlation between feelings of comfort and accomplishment, there seemed to be negative correlation at the +20 dB levels under frequency manipulation. Considering the comments from the participants, the comfortable feeling seems to come from the cues that imply that the teeth have been cleaned and it is not necessary to brush them anymore. This feeling may be induced by presenting high-frequency components of the brushing sounds that evoke sensation of a dry and smooth surface as described in the comments. This agrees with the known parchment-skin illusion (Jousmäki and Hari, 1998). In contrast, the score for the feeling of accomplishment decreased as the participants felt that they did not have to brush their teeth anymore and that their teeth had already been cleaned. For the 1000 Hz condition, the participants seemed to feel something sticky, like food debris, on their teeth. They felt uncomfortable and dislodging this by brushing induced a sense of accomplishment. However, for the 500 Hz condition, participants seemed to perceive that their teeth, or the bristles, were too soft to identify. This caused them to feel uncomfortable and no longer provided the idea that they were dislodging something.

The summary of our experimental findings are as follows. When the sound level was amplified:

- Low-frequency sounds induce uncomfortable feelings, but also feelings that the teeth are brushed well.
- High-frequency sounds induce comfortable feelings, but also feelings that the teeth were not brushed at all.

These findings allow us to control and design the impressions made by toothbrush during the brushing process. We expect that gradually increasing the frequency according to the number of strokes brushed will result in more comfortable and accomplished feeling as the users can vividly perceive the cleaning process from “dirty” to “clean”.

Experiment 2: Does changing the filtering frequency improve the total user experience?

To investigate the effects of changing the frequency of the brushing sounds according to brushing action on the total user experience, we conducted an experiment in which participants evaluated their feelings of comfort and accomplishment from brushing. Although sound modulation should be applied according to tooth staining (e.g., plaque volume), for the ease of this experiment, modulation was applied according to brushing time.

Setup

Toothbrush. In this experiment, we used a piezo contact microphone (EGT-101, Kikutani Music Co., Ltd., Aichi, Japan), instead of the capacitor microphone that was used in Experiment 1 to record only the brushing sounds. These reflect the comments from Experiment 1 where one comment noted that “environmental sounds captured by the microphone were uncomfortable”. The microphone was embedded into the head of the handle and connected to an amplifier (Morris Preamp 20, Moridaira Co., Ltd., Tokyo, Japan). The other configuration was the same as that in Experiment 1.

Sound processing. We used Max as the sound processor. For the brushing sound feedback, we used a band pass filter. We prepared two sequential conditions with a constant Q value of 1.0. When the peak frequency was shifted from low to high, it was called the low-high condition. In the low-high condition, the change of frequency from 1000 to 8000 Hz took 10 seconds, where the time counted the duration that the user was brushing their teeth. The frequency range was determined based on results of Experiment 1 so that participants would feel that their teeth are gradually becoming cleaner. We also prepared an unfiltered condition and a high-low condition as control conditions. In the high-low condition, we expect that the scores would be lower than for the unfiltered condition as participants would feel that their teeth gradually become dirtier.

We prepared three sound level conditions (0, +10 and +20 dB). We removed the -20 dB condition as it was found to be too soft in Experiment 1. The +10 dB condition was added to provide a data point between 0 dB (soft) and +20 dB (loud) conditions. The default sound level was set at approximately 75 dB (A) using a sound level meter. For the other conditions, the sound levels were set by Max.

The beep warning sound when grip force was excessive was prepared as in Experiment 1. We also included another beep sound (2000 Hz sinusoidal wave) to notify the end of a trial.

Environment. The environment was the same as that of Experiment 1.

Procedure

The participants were instructed on how to brush their teeth as in Experiment 1. Instead of five strokes, they were asked to brush their teeth until they heard the 2000-Hz beep. The rating process was the same as Experiment 1 (the standard condition was unfiltered at 0 dB).

Each participant performed this evaluation task 27 times; (two sequential conditions + one non-filter condition) × three sound gain conditions × three repetitions). Comparative conditions were randomly presented and participants were unaware of the parameters.

Before the trials, the participants practiced the procedure several times without the headphones. After every three trials, they ate a piece of potato chip, chewing on the left side to keep their teeth dirty. They were allowed to rinse their mouths freely during the experiment. After the trials, an open question was asked of participants.

Seven participants—four men and three women—aged between 21 and 26 (mean =23.1; SD = 1.9) took part in the experiment. All participants were right-handed. Three of them also took part in Experiment 1.

Results

Feeling of comfort. The results of the analysis of feelings of comfort for the three sound gain conditions with respect to the three sequential conditions are shown in Figure 8. A two-way within-participants repeated measure ANOVA was performed on the data. The within-participants factors were Sequential Manipulation (i.e., high-low, non-filter and low-high conditions) and Sound Gain (i.e., 0, +10 and +20 dB).

The main effects of Sequential Manipulation ($F(2, 12) = 8.08$; $p < 0.01$) and Sound Gain ($F(2, 12) = 8.70$; $p < 0.01$) were significant. The interaction between the Sequential Manipulation and Sound Gain was significant ($F(4, 24) = 4.00$; $p < 0.05$). Simple main effects were noted when Sound Gain was set to high-low ($F(2, 12) = 7.97$; $p < 0.01$; +20 dB > +10 and 0 dB (Bonferroni-corrected t-tests where $p < 0.05$ prior to correction)) and low-high ($F(2, 12) = 16.29$; $p < 0.01$; +20 and +10 dB > 0 dB) conditions and for Sequential Manipulation at the 0 dB ($F(2, 12) = 4.54$; $p < 0.05$; low-high > high-low), +10 dB ($F(2,12) = 9.47$; $p < 0.05$; unfiltered and low-high > high-low) and +20 dB ($F(2, 12) = 6.02$; $p < 0.05$; low-high > high-low and unfiltered).

Feelings of accomplishment. The results of the analysis of feelings of accomplishment for the three sound gain levels with respect to the three sequential manipulation conditions are shown in Figure 9. An ANOVA was performed on these data similar to that performed on feelings of comfort.

The main effects of Sequential Manipulation ($F(2, 12) = 5.64$; $p < 0.05$) and Sound Gain ($F(2, 12) = 10.50$; $p < 0.01$) were significant. The interaction effect between Sequential Manipulation and Sound Gain was significant ($F(4, 24) = 3.09$; $p < 0.05$). Simple main effects were noted for Sound Gain under the high-low ($F(2, 12) = 5.79$; $p <$

Figure 8 Mean values of the feeling of comfort for the three sound gain levels with respect to the three sequential conditions. Error bars denote standard deviation.

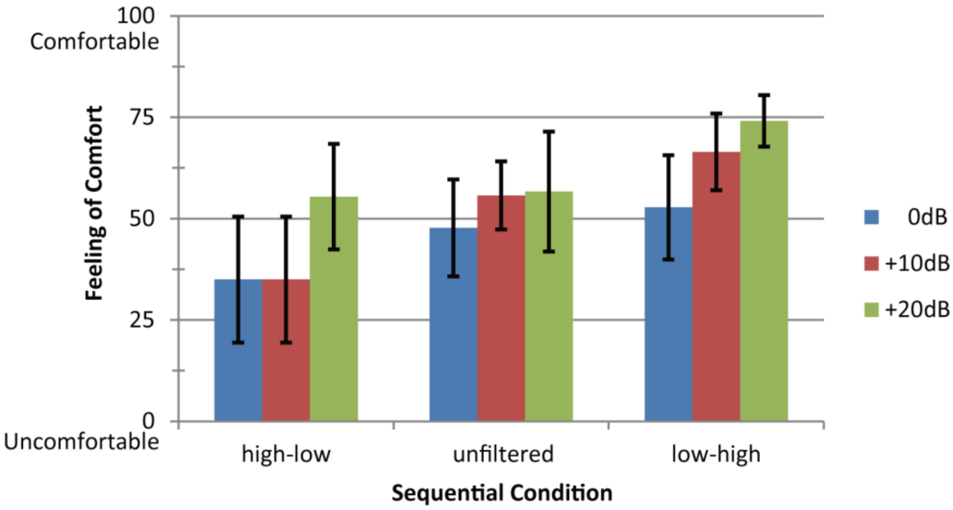


Figure 9 Mean values of the accomplished feeling for the three sound gain levels with respect to the three sequential conditions. Error bars denote standard deviation.

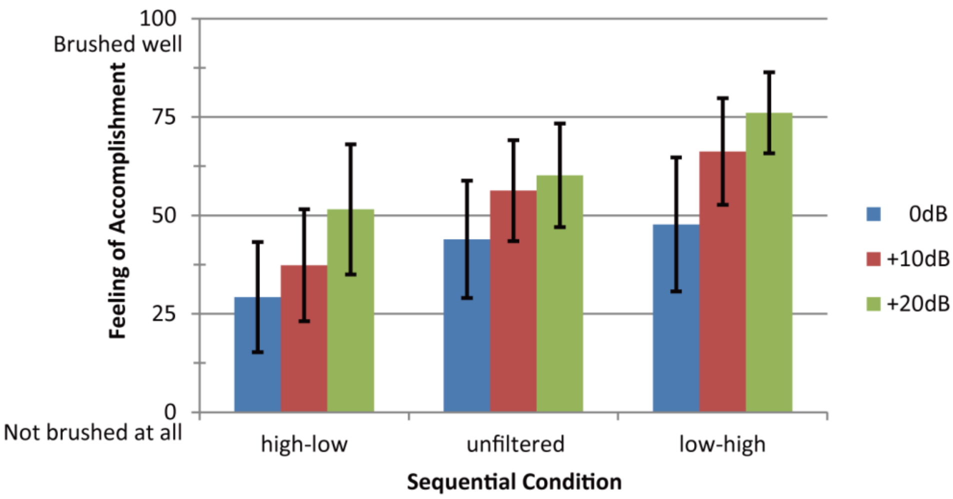


Table 2 Comments from participants for an open question after Experiment 2

Comments	No.	Comments	No.
Louder sounds were comfortable.	3/7	Sequentially raising frequencies were comfortable.	2/7
Louder sounds provided feelings of accomplishment.	4/7	Sequentially raising the frequency provided feelings of accomplishment.	3/7
Low-frequency sounds induced me to apply more force to the teeth.	2/7	There were conditions that made me feel as if my teeth had become dirtier.	1/7
Low-frequency sounds provided feelings of accomplishment.	1/7	Collision sounds produced by the brush and the teeth were uncomfortable.	2/7
High-frequency sounds were comfortable.	2/7	I felt a delay between brushing and sound presentation.	1/7
High-frequency sounds provided feelings of accomplishment	2/7	I brushed so much that my teeth were painful.	2/7

0.01; +20 dB > 0 dB (Bonferroni-corrected t-tests where $p < 0.05$ prior to correction)), unfiltered ($F(2, 12) = 4.44$; $p < 0.01$; +20 dB > 0 dB), and the low-high ($F(2, 12) = 28.01$; $p < 0.01$; +20 dB and +10 dB > 0 dB) conditions, and for Sequential Manipulation at the +10 dB ($F(2,12) = 6.67$; $p < 0.05$; the posthoc test found no significance) and +20 dB ($F(2, 12) = 5.91$; $p < 0.05$; low-high > high-low).

Open Question. Table 2 shows the comments from participants when asked an open question after the experiment. Unlike Experiment 1, there were no negative comments for the louder sounds. Considering the two parameters, the +20 dB level provided the best sound gain, despite expecting +10 dB level to be this case.

There were positive comments for the low-high condition. One of the participants also reported that there were some conditions that made him feel as if his teeth were getting dirtier while he brushed. The conditions he mentioned were probably high-low conditions.

Discussion

The results from Experiment 2 provided two major findings. The first was that higher sound levels induced more comfortable and accomplished feelings. This finding was different from that of Experiment 1 where the +20 dB conditions were felt to be too loud and uncomfortable, and provided less accomplishment. One of the explanations for this situation would be that using the piezo contact microphone reduced irrelevant environmental sounds that were amplified and noisy in Experiment 1.

The other finding was that sequentially raising the frequency (i.e., low-high condition) induces the most comfortable and accomplished feelings. From Experiment 1, in low-high conditions, participants first started with uncomfortable feelings as their teeth felt dirty and they felt as if they were cleaning up debris. As the frequency rose, they felt more comfortable as their teeth were becoming clean. Finally, as the cleaning process became more vivid, they felt feelings of accomplishment. As a result, participants rated the total experience as both comfortable and for providing feelings of accomplishment.

Interaction effect between the sequential manipulation and sound gain occur and the best was the low-high and +20 dB condition. The values of the two scales increased by approximately 1.5 times compared with the standard condition (unfiltered and 0 dB). The worst was the high-low and 0 dB condition as values decreased by 0.5-0.75 times. This large variation was not observed in Experiment 1. This implies that the contribution of sequential manipulation would be greater than the sound gain. However, a precise comparison of results between the two experiments is not feasible as the setup was different.

There were two types of comments that referred to the limitations of the current setup. One noted that the delay between brushing and sound presentation, which was mainly due to the software sound processing. One participant reported that the delay disturbed the brushing rhythm, which might have affected the evaluation.

The other comment regarded pain. In the experiment, we asked participants to brush the same teeth to minimize the influence of external factors. This induced a painful sensation for some participants. Though decreasing the number of trials may relieve this pain, it reduces the number of factors for analysis. The current trial takes about 30 minutes and seems to be optimal.

Conclusion

This paper first addressed the current issues with tooth brushing, particularly in regard to the quality of feedback. We develop a novel approach to alter the impressions of tooth brushing by modulating the brushing sounds. In the first experiment, we demonstrated that increasing the sound gain and manipulating the frequency affects tooth brushing impressions in terms of feeling of comfortable and accomplished. In the second experiment, we demonstrated that brushing sounds that increase infrequency induce more comfortable and accomplished feelings than do standard sounds. Our results show that it is possible to motivate the user by designing an interactive method that leaves impressions when brushing teeth. Our approach can be used to correctly teach tooth brushing by presenting positive or negative impressions when the user correctly or incorrectly brushes their teeth.

The current setup is not practical for daily use as plugging a cord into the toothbrush and wearing headphones can be cumbersome. Our next step is to implement our proposal with a wireless toothbrush. A possible implementation may use a bone conduction speaker like Tooth Tunes (Arm & Hammer Spinbrush, 2012). We would also like to conduct a long-term user study to determine whether our approach is compatible with daily life.

Acknowledgement

This work was supported by JSPS KAKENHI Grant No. 24004331.

References

Bass, C.C. (1954) 'An effective method of personal oral hygiene; part II', *Journal of the Louisiana State Medical Society*, Vol. 106 No. 3, pp. 100 - 112.

Chang, Y.C., Lo, J.L., Huang, C.J., Hsu, N.Y., Chu, H.H., Wang, H.Y., Chi, P.Y., and Hsieh, Y.L. (2008) 'Playful toothbrush: ubicomp technology for teaching tooth brushing to kindergarten children' in the *SIGCHI Conference on Human Factors in Computing Systems*, Florence, Italy, pp. 363 - 372.

Guest, S., Catmur, C., Lloyd, D., and Spence, C. (2002) 'Audiotactile interactions in roughness perception', *Experimental Brain Research*, Vol. 146 No. 2, pp. 161 - 171.

Hachisu, T., and Kajimoto, H. (2012) 'Augmentation of toothbrush by modulating sounds resulting from brushing' in the *International Conference on Advances in Computer Entertainment Technology*, Kathmandu, Nepal, pp. 31 - 43.

Hashimoto, Y., Inami, M., and Kajimoto, H. (2008) 'Straw-like user interface (II): a new method of presenting auditory sensations for a more natural experience' in *Proceedings of the International Conference on Haptics*, Madrid, Spain, pp. 484 - 493.

Iwata, H., Yano, H., Uemura, T., and Moriya, T. (2004) 'Food simulator: a haptic interface for biting' in *Proceedings of the IEEE Virtual Reality*, Chicago, IL, USA, pp. 51 - 57.

Jousmäki, V., and Hari, R. (1998) 'Parchment-skin illusion: sound-biased touch'. *Current Biology*, Vol. 8(6), pp. 190.

Koizumi, N., Tanaka, H., Uema, Y., and Inami, M. (2011) 'Chewing jockey: augmented food texture by using sound based on cross-modal effect' in *Proceedings of the International Conference on Advances in Computer Entertainment Technology*, Lisbon, Portugal, Vol. 21.

Lederman, S.J., Morgan, T., Hamilton, C., and Klatzky, R.L. (2002) 'Integrating multimodal information about surface texture via a probe: relative contributions of haptic and touch-produced sound sources' in *Proceedings of the Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, Orlando, FL, USA, pp. 97 - 104.

Nakajima, T., Lehdonvirta, V., Tokunaga, E., Ayabe, M., Kimura, H., and Okuda, Y. (2007) 'Lifestyle ubiquitous gaming: making daily lives more plesurable' in *Proceedings of the 13th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications*, Daegu, Korea, pp. 257 - 21.

Oral-B Professional Care SmartSeries 5000 with SmartGuide Electric Toothbrush. [online] http://www.oralb.com/products/professional-care-smart-series-5000/ (Accessed 5 April 2013) Oral-B(2009).

Tooth Tunes. [online] http://www.spinbrush.com/Toothtunes.html (Accessed 5 April 2013) Arm and Hammer Spinbrush (2012).

Zampini, M., Guest, S., and Spence, C. (2003) 'The role of auditory cues in modulating the perception of electric toothbrushes'. *Journal of Dental Research*, Vol. 82 No. 11, pp. 929 - 932.

Zampini, M., and Spence, C. (2005) 'The role of auditory cues in modulating the perceived crispness and staleness of potato chips'. *Journal of Sensory Studies*, Vol. 19 No. 5, pp. 347 - 363.