Effect of Feedback Medium for Real-time Mastication Awareness Increase using Wearable Sensors

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Keywords: Mastication, Bone-conduction Microphone, Eating Quantification, Persuasive System, Real-time Feedback.

Abstract: Increasing the number of mastications can help suppress obesity, but it is difficult to keep constant awareness of it in everyday life. Besides, the conventional mastication number measurement apparatus is large and non-portable such it is difficult to use it in daily life. This research proposes a system that supports chewing and utterance consciousness improvement in real-time. It is composed of a cheap and small bone conduction microphone to collect sound intra-body sound signal, and a smartphone that processes sound and provides feedback in real-time so that it can be used conveniently in daily life. First, the accuracy of mastication counting and utterance length estimation has been evaluated, confirming to be sufficient to provide real-time feedback. Second, the evaluation of the effect on chewing and utterance consciousness of different ways and medium of real-time feedback during a meal was carried out. It was possible to clarify the impact of real-time feedback, as well as to determine the factors that affect more efficiently the improvement of mastication number and utterance.

1 INTRODUCTION

Obesity may cause lifestyle diseases such as diabetes and heart disease. The Japanese Ministry of Health, Labor and Welfare has taken measures for this prevention, but the number of obese patients has not decreased compared to 10 years ago (MHLW, 2016). As measures against obesity, it is known to be useful to improve eating habits and exercise moderately, but it is also possible to significantly prevent it by increasing the number of mastications (Ando et al., 2008; Nicklas et al., 2001). As a concrete example, when attempting to improve mastication activity for young Chinese men with obesity, it was possible to reduce the intake of energy in all the subjects consistently (Li et al., 2011). The same study also demonstrated that there is a useful possibility of measures against obesity by the activity of increasing the number of chewing.

Improvement in the mastication amount is also crucial since healthcare experts always check the number of chewing as well as meal duration and food type as an indispensable factor in assessing dietary habits. In addition to the above, to prevent obesity, the nervous system and chewing activities are closely related. This relation is because chewing repetition stimulates the satiety center and sympathetic nervous system, which can reduce obesity by secreting hormones that suppress appetite (Kao, 2007). Notably, several past works have reported that people with fast-eating have higher tendency to be obese, which is partly because lowering secretion of hormones by eating fast causes an increase in dietary amount (Denney-Wilson and Campbell, 2008; Gaul et al., 1975). In addition to this, it is considered desirable to encourage utterances during meals. Indeed, Kishida et al. have reported that making conversation during meals is related to good health (Kishida and Kamimura, 1993).

This research proposes a system that supports chewing and utterance consciousness improvement in real-time. It is composed of a cheap and small bone conduction microphone to collect sound intra-body sound signal, and a smartphone that processes sound and provides feedback in real-time so that it can be used conveniently in daily life. Though chewing and swallowing processes depend on many factors both human and food property dependants (see (Logemann, 2014)), this paper focuses the attention on the point that in identical ”food conditions” (content, amount, etc.) adequate real-time feedback of mastication amount and utterance duration has a positive effect on the quantitative and qualitative improvement of both behaviors.

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2 STATE-OF-THE-ART

Many studies have been focusing on chewing as an improvement of dietary habits, mainly proposing various methods and devices to quantify mastication activity with little burden. As an effort to improve such nutritional habits, eating habit improvement systems using wearable devices have been proposed, but there is still room for improvement in judging mastication amount and utterance duration when used in everyday life(Amft et al., 2005; Shuzo et al., 2010; Zhang et al., 2011).

As previous works on mastication counting have shown, current devices that measure myoelectric potential from the masseter muscle can count bite, but wearing the apparatus in daily life is a significant burden for the user (Kohyama et al., 2003). Another technique using infrared sensor can detect small changes in temporal muscle tension, but one can consider that this method is not applicable in the sense that it bothers users during meals due to the sensing medium and the appearance (Obata et al., 2002). Similarly, Tanigawa et al. explored the use of the Doppler effect in their system to sense the Doppler signal of mastication produced from vertical jaw movements (Tanigawa et al., 2008). However, there also some calibration is required.

Recently, analysis of internal body sounds spectra has attracted attention as a way to differentiate between biting and speaking activities, and to classify several types of food with less burden (Mizuno et al., 2007). Uno et al. Proposed a system to detect the chewing frequency and bite fidelity using bone conduction microphones(Uno et al., 2010). Paying attention to the amplitude during chewing, it is a system that judges chewing when amplitude magnitude exceeds a certain level, and the judgment accuracy was about 89%. However, activity discrimination method is limited to specific ailments. Similarly, Nishimura et al. (Nishimura and Kuroda, 2008) and Faudot et al. (Faudot et al., 2010) propose to measure the chewing frequency using a wireless and wearable in-ear microphone. However, to estimate the number of chewing operations, still, some parameters need to be adjusted by the user each time, which is a severe constraint in practical use.

Inoue et al. have proposed a method of overwriting the visual appearance of food and the acoustic signature of mastication sound during eating using an head-mounted display (HMD) and a bone conduction speaker(Inoue et al., 2016). Using the HMD, they tried to increase the number of chewing by superimposing an indication of texture that makes food feel stiff and regenerating chewing sound which makes it feel solid in bone conduction speaker. As a result, they reported that audiovisual information overwriting issued an increase in the number of chewing. Similarly, Kumagai et al. developed a game as an opportunity making medium to increase the number of chewing (Kumagai et al., 2016). Since a personal computer (PC), an HMD, a charge amplifier, etc were components commonly used in the above two related studies, the apparatus was large and difficult to handle in daily life. In most current systems and approaches, measurement of conversation time depends on environmental sounds, so there is room for improvement in determination accuracy. Also, even if some works are doing real-time measurements, feedback display is not done in real time.

3 PROPOSED SYSTEM

3.1 System Outline

Based on the above review of related research, it has been decided to use a bone-conduction microphone to enable the collection of both chewing and utterance activities information. Some of the hands-free headsets available on the market are integrating such specific microphone, making it easily accessible to everyone. Moreover, Fontana et al. have shown earlier that even a strain sensor to detect chewing events and a throat microphone to detect swallowing sounds present enough comfort levels, such the presence of the sensors does not affect the meal (Fontana and Sazonov, 2013). A smartphone is used to deal with the real-time processing of the collected sound signal. The algorithm that counts the mastication number and estimates the duration of utterance, though designed based on previous works, has been tuned focusing on light computation to enable real-time processing. Though the accuracy of the proposed system is not the main topic of this paper, an initial evaluation has been carried out to confirm it is accurate enough to give quantified information about chewing and utterance that is not too far from that perceived by the user.

The proposed support system has been separated mainly into two sub-systems that are, a mastication number improvement support interface, and an utterance awareness improvement device. Figure 1 shows the usage image of the mastication number improvement support sub-system. In addition to the bone-conduction microphone (Motorola finiti Bluetooth headset) attached to one ear and the smartphone (Motorola Moto G) to process sound signal, the chewing frequency improvement support sub-system uses the same smartphone or a smartwatch (Motorola Moto 360) to provide real-time feedback. Figure 2 shows the usage image of the support sub-system for utterance awareness improvement. In addition to the smartphone, it uses a microphone to collect sound signal and provides real-time feedback about utterance duration using whether the smartphone display, a vibration device or a Light Emitting Diode (LED). Arduino compatible micro-controllers were used to control the input of the microphone, and activate whether the vibration element or the LED simultaneously.

3.2 Method for Real-time Measurement of Mastication Count and Utterance Duration

Figure 3 shows the overall flow of the measurement algorithm for mastication count and speech time. The main algorithm, though designed based on previous works, has been tuned focusing on light computation to enable real-time processing. Short-term energy was calculated from the raw sound signal and the resulting data used for differentiation of mastication and utterance signals. Calculation formula of Short-Term Energy is described in Equ.1, where ”s” is the processed raw signal, ”n” the step size in sample numbers, and ”w(n)” the windowing function. Short-Term Energy makes it easier to grasp the characteristics differences by explicitly checking the magnitude of the resulting wave signal. Therefore, by simplifying the waveform and making the waveform of the sound data acquired by this system easier to interpret quantitatively, it is possible to capture the features of mastication and utterance. From the data obtained by Short-Term Energy, we measured the chewing count and utterance time using both a magnitude threshold and a duration threshold set by calibration.

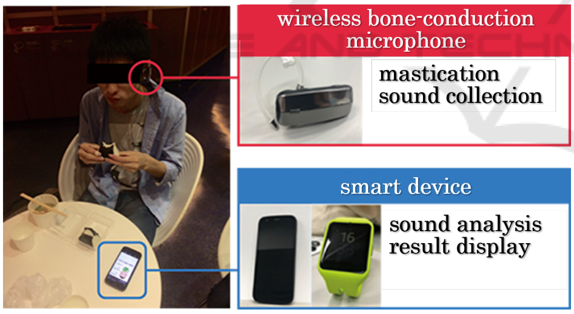

Figure 1: Usage image of mastication number improvement support system.

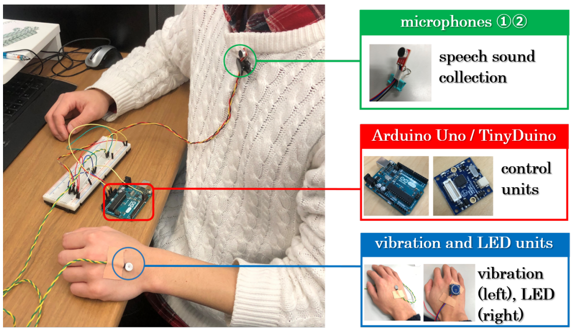

Figure 2: Usage image of utterance awareness improvement support device.

$$E(n) = \sum_{m=-\lim\inf}^{\lim\inf} \left(s(m) * w(n-m)\right)^2 \qquad (1)$$

Measurement of chewing count and utterance duration is performed as follows. The outline of the process consists in repeating the following succession of operations in real-time during the meal: sound signal collection, short-term energy calculation, mastication and utterance differentiation, result feedback. The measurement starts after the microphone is set and

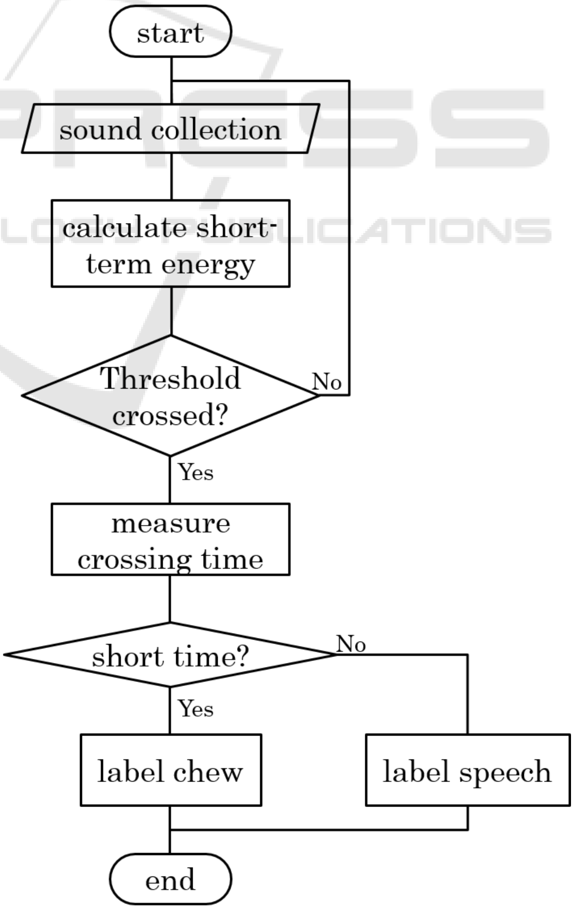

Figure 3: Overall flow of chewing and utterance determination algorithm.

connected by pressing the ”start” button of the dedicated smartphone application, and it ends by pressing the ”end” button of the application. Figure 3 shows the overall flow of the algorithm for mastication and utterance activities differentiation.

As shown in Fig. 3, when the calculated short-term energy value exceeds the threshold value, discrimination and calculation of mastication and utterance are performed. In the case where the calculated values exceed the set threshold value for more than a fixed timespan, the algorithm judges the current sound segment an utterance. The segment ends once the calculated value falls below the threshold, and the algorithm provides the utterance duration to the interface for real-time feedback before looping again. In the case where the computed values exceed the set threshold but only within a fixed timespan, the algorithm judges the current sound segment as a chew and increases the total number of mastications. Then the algorithm provides this total number of bites to the interface for real-time feedback before looping again. Fig. 4 shows examples of the signal after short-term energy calculation and the timing to separate mastication and utterance sound segments.

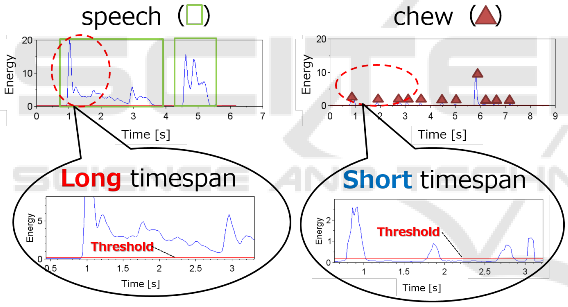

Figure 4: Determination of mastication and utterance and separation.

4 EVALUATION EXPERIMENT

4.1 Experimental Outline

Evaluation experiments were conducted to not only verify the accuracy of the above-described algorithm, but also to clarify the influence of the different real-time feedback interfaces and medium on mastications number and utterance awareness. Table 1 shows the correspondence of each feedback tested. Patterns A, B, and C were used in the sub-system that promotes mastication, while patterns D, E, and F were used in the sub-system that promotes utterance. Figure 5 shows screenshots of the smartphone displays for pattern A and B.

Table 1: Description of the six feedback contents.

	feedback content	device
A	picture animation and gauge change according chewing count	smartphone smartphone
B	chewing count	smartphone
C	pattern A	smartwatch
D	speech time	smartphone
E	vibration according speech time	vibration unit
F	LED lighting according speech time	LED unit

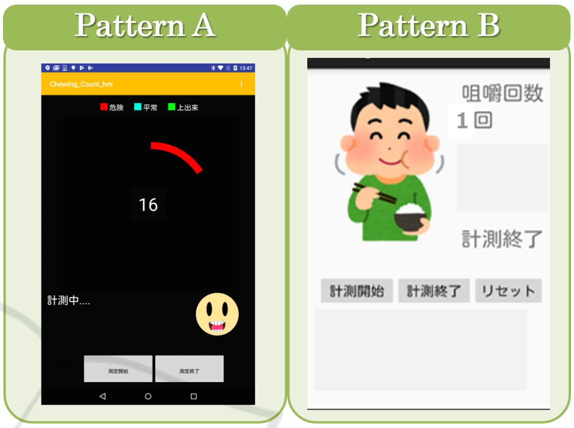

Figure 5: Screenshots of smartphone screen’s feedback patterns A (left) and B (right).

An experimental study about mastications count and utterance duration feedback has been carried out on 18 males subjects from 22 to 23-year-old. During each experiment, the subjects ate provided food with the ear-worn device attached and answered the questions of the experimenter during meals for utterance production. Two cases were presented, namely, when presenting feedback using the proposed system during meals and not presenting feedback. In both cases, the ear-worn device was attached. The meal content, two rice balls and shredded cabbage (60g x 2) were divided and distributed respectively to nine subjects each. In the experiment with real-time feedback, subjects have been divided into three groups, such among feedback patterns A, B, and C, each has been provided to six subjects respectively. Simultaneously, experiments on utterance time have been performed. Due to some equipment trouble, only 14 subjects data were collected. Seven subjects were provided patterns D and E, and seven others patterns E and F respectively. However, feedback pattern D had no experimental equipment trouble such the whole 18 subjects data were available to evaluate the accuracy of utterance duration estimation. Exact values of mastication count and utterance time were measured using video recorded by a video camera.

In addition to the above, subjective evaluation using a questionnaire survey was conducted to evaluate whether the user was conscious of the utterance by feedback on the utterance time. Each question was answered using the five-point scale. Furthermore, to verify whether the user was aware of speaking, Fisher's exact test of the independence between pattern E and pattern F was performed on the item ”Were you aware of an utterance during meals?”. Similar subjective evaluation was also carried out in mastication improvement sub-system experiments.

4.2 Experimental Results

Table 2 shows the results for the real-time detection accuracy of mastication and utterance sound segments using the proposed system. Bites could be counted with sufficiently high efficiency with an average accuracy of 91%. Concerning utterance duration, the overall average accuracy was about 96%, which was also considered high enough to provide feedback in accordance with user's perception.

Table 3 shows the result of mastication amount increase result when providing feedback compared to no feedback. An increase could be confirmed for all 18 subjects, whatever the feedback and food types are. Relatively to each subject, mastication amount was significantly increased ($p < 0.01$, n=18) by about 16% with real-time feedback compared with the case without feedback. Since the data set has two parameters, the food type, and the feedback pattern, a two-way statistical analysis of variance (ANOVA) has been performed. Table 4 shows the result of the ANOVA. The p-value of the feedback pattern, 0.02, is small enough to indicate strong evidence of its effect on average mastication amount increase. On the other hand, the p-value for the food type, 0.69, is big, indicating it does not affect mastication amount increase. Also, since the p-value for the interaction term, 0.89, is big, indicating the effect of feedback pattern does not depend on food type.

Then, a multiple comparison test (alpha=0.05, Bonferroni method) of the mean mastication amount increase depending on each feedback pattern has been performed to see if the were any significant difference in the effect of each feedback pattern (5). As a result, the mean mastication amount increase in case of feedback pattern A is significantly higher than in case of feedback B p-values 0.028. The p-value of the mean difference between feedback patterns A and C, 0.066, though over 0.05, is small enough to indicate the more significant effect of feedback pattern A. Concerning the difference between feedback patterns B and C, the large p-value suggests there is no difference between them.

Table 2: Chewing count and speech duration detection accuracy.

	chew count	speech duration
detection accuracy (%)	91	96
standard deviation (%)	4	3

Table 3: Mastication amount increase result depending on feedback pattern.

food type	subject	feedback pattern	mastication increase amount
2 rice balls	1	A	46
	2	A	31
	3	A	32
	4	B	29
	5	B	6
	6	B	22
	7	C	15
	8	C	22
	9	C	23
shredded cabbage (60gx2)	10	A	27
	11	A	34
	12	A	46
	13	B	23
	14	B	20
	15	B	18
	16	C	19
	17	C	14
	18	C	41

Table 4: Analysis of Variance (2-ways ANOVA) ANOVA of the mastication amount increase depending on food type and feedback pattern.

source of variance	sum of squares	degrees of freedom	mean squares	F	p>F
Feedback pattern	921	2	460.7	5.18	0.02
Food type	14	1	14.2	0.16	0.69
Feedback⋆Food	21.8	2	10.9	0.12	0.89
Within factors	1066	12	88.9		
Total	2024	17			

Table 5: Multiple comparison test of the mean mastication amount increase by each feedback pattern.

compared patterns		CI 95% (low)	means difference	CI 95% (high)	p-value
A	B	1.8	16.3	30.8	0.028
A	C	-0.9	13.7	28.2	0.066
B	C	-17.2	-2.7	11.9	0.877

Table 6: Question contents and corresponding evaluation items.

Was chewing count correct?	accuracy
Did you feel uncomfortable with the mounted device? Wasn't this system troublesome?	tiresomeness, oppressiveness
Was the screen easy to see?	easiness to understand
Do you want to use this system in the future?	practicability

Additionally, as a result of subjective evaluation of speech experiment, utterance awareness increased for more than half of the subjects in the condition of using the utterance awareness improvement support sub-system. Table 6 shows the items corresponding to the question contents. The results of subjective evaluation on chewing performed in the experiment using the proposed system are shown in Figure 6. From this result, it was possible for the subjects to be aware of mastication during eating without feeling uncomfortable with the ear-worn device. Besides, it could be confirmed that there is no particular problem in the accuracy and understandability of the proposed system. Subsequently, the results of the subjective evaluation of speech are shown in Figure 7 and Figure 8.

In this experiment, in order to clarify the difference of the awareness with respect to the utterance feedback, Fisher's exact test was carried out for patterns E (vibration) and F (LED). In Fisher's exact test, the five-point scale resulting from subjective evaluation is divided into two categories of ”good” and ”bad”, excluding ”neither” items. ”good” associated with ”I strongly agree” and, ”I think so,” while ”bad” with ”I do agree” and ”I strongly disagree.” As a result, there was a tendency of a significant difference in feedback by pattern E and pattern F (p <0.1) (Table 7). Regarding the feedback of Pattern D, subjective evaluation was performed only on the item ”Was the system correctly measuring speech?” (Fig. 9).

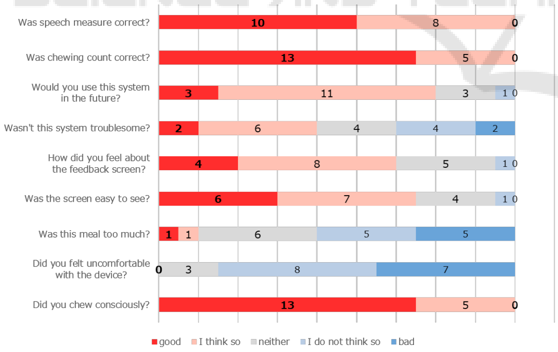

Figure 6: Results of subjective evaluation on chewing.

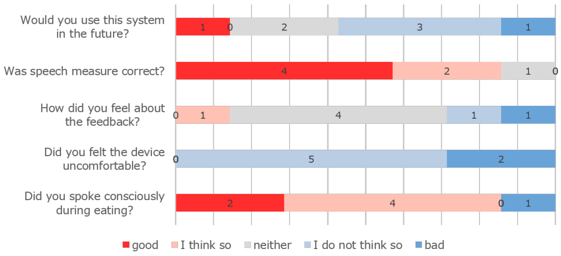

Figure 7: Results of subjective evaluation of feedback by vibration element.

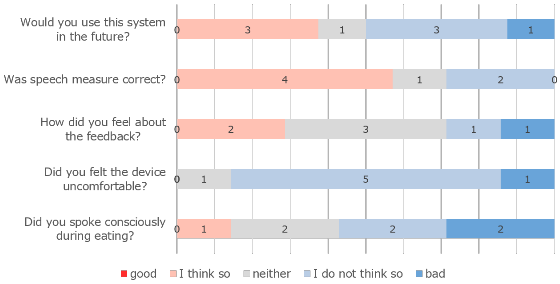

Figure 8: Results of subjective evaluation of feedback by LED.

Table 7: Subjective evaluation of Fisher's exact probability distribution.

	Good	Bad
vibration	6	1
LED	1	4

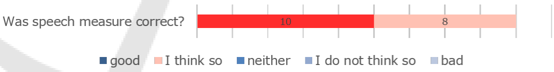

Figure 9: Results of subjective evaluation about utterance accuracy.

5 DISCUSSION

5.1 Accuracy of Mastication and Utterance Discrimination

As described in the experimental results, the accuracy of chewing determination in real time was about 91%. This result improved the accuracy of about 2% when compared with about 89% of judgment accuracy of bites count in our previous research (Mitsui et al., 2017). Also, the accuracy of utterance judgment was improved compared to previous studies. According to the result of the subjective evaluation, regarding the chewing, there were many positive results such as

”I strongly agree” or ”I agree” for the question ”Was chewing count correct?” Based on this result, it can be said that chewing was able to be counted without letting the subject feel uncomfortable. However, the accuracy of the proposed system may change depending on the surrounding environment. In this experiment, the accuracy was good because it was carried out in a quiet room, but there is a drawback that if the surroundings are noisy, that noise sound is also collected.

As for the utterance, according to the result of the subjective evaluation, it can be said that subjects were able to measure without discomfort because accuracy on Android was mostly positive in subjective evaluation as well. However, in the case of measurement by Arduino micro-controller, the problem is that the microphone picks up noise, exceeds the threshold value, and the code connection method is inappropriate. As a countermeasure, it is conceivable to utilize the excellent accuracy of the utterance of Android, to connect Arduino micro-controller to Bluetooth, and to provide feedback.

5.2 Impact on Meals with or without Feedback

The number of mastications significantly increased by an average of 16% with real-time feedback. As a result, it became clear that it is possible to increase the number of mastications significantly through visual feedback. One of the reasons that the number of chewing is increasing is that the user becomes more conscious of chewing during meals due to feedback.

Though the mastication amount increased for all subjects in all real-time feedback patterns, a significantly higher average increase was observed for feedback pattern A compared to feedback patterns B and C, between which no significant difference was found. Based on this results, considering the differences in the device used and interface design between the three feedback patterns, it is likely that the parameters such as a more significant amount of information and larger screen size influence more the user to be conscious of ”chewing.” In the former case, the information amount due to the feedback in the pattern A and pattern B is more significant in pattern A, and as a result, the amount of mastication significantly increases more. In the latter case, though pattern A and pattern C have the same feedback content, feedback pattern A that is provided using a smartphone has a significantly higher increase of the mastication amount than feedback pattern C that is provided using a smartwatch.

According to the result of the subjective evaluation, the subjects are more conscious of their utterance. Also, regarding Fisher’s exact test, there is a tendency that pattern E (vibration) is significantly more efficient than pattern F (LED). In the case of pattern F, if the LED is slightly remove the line of sight, feedback does not make sense, whereas, in the case of pattern E, it is easier to force the subject to be conscious.

6 CONCLUSIONS AND FUTURE WORKS

As a chewing promotion system usable in everyday life, we proposed a system that presents feedback of chewing frequency in real time using bone conduction microphone and smartphone, and a device to promote speech. In implementing the proposed system, we constructed an algorithm for measuring chewing frequency and utterance, confirmed the accuracy of judging the number of chewing and speech time in the proposed system, and the influence of feedback from the proposed system on meals. As a result, we succeeded in judging the chewing frequency with about 91% judgment accuracy which is about 2% higher than the previous study. Meanwhile, the duration of utterance can be measured with an high precision of about 96%. Besides, the feedback coordinated with the utterance using Arduino micro-controller controlled wearable devices enabled to make more than half of the subjects aware of the utterance. Also, there were a difference in utterance awareness depending on feedback medium, showing that vibration stimuli was more efficient than visual stimuli. However, in the feedback on utterances, there was a tendency to have negative responses to the question ”Would you use this system in the future”? For this reason, it is necessary to develop a different feedback medium taking into account the user practicality.

As a prospect, we want to improve the count accuracy of mastication in real meal environment (loud places, various foods) and also consider a feedback medium with higher visibility and more significant effect to the user. Furthermore, we would like to conduct a long-term experiment using the proposed system and verify its effectiveness.

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