Eating Habit Improvement System Using Dietary Sound

Haruka Kamachi[1][a], Sae Ohkubo[2][b] and Anna Yokokubo[1,2][c] and Guillaume Lopez[1,2][d]

[1]*Graduate School of Science and Engineering, Aoyama Gakuin University, Sagamihara, Japan*

[2]*Department of Integrated Information Technology, Aoyama Gakuin University, Sagamihara, Japan*

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Abstract: Obesity may cause lifestyle diseases such as diabetes and high blood pressure. Eating slowly and chewing well are essential to prevent obesity. This research aims to improve the consciousness of dietary behavior based on eating habits by quantifying eating behavior. It proposes "ChewReminder," a smartphone application software that detects eating activities in real-time under a natural meal environment and gives feedback based on detected activity. ChewReminder detects four activities: chewing, swallowing, talking, and other.The smartwatch gives feedback using vibration depend on chewing count per one bite which information was linked from the smartphone. Also, the total feedback about the meal was displayed on the smartphone after finishing the meal. The chewing count for 70% subjects and chewing pace for more than half subjects was improved with using ChewReminder by the result of total chewing count, average of chewing count per bite and chewing pace. ChewReminder is effective especially people who are aware of fast eating. Also, the result of long-term experiment indicated that feedback displayed on a smartphone was effective to improve consciousness of eating activity. Therefore, the result of both experiment shows that ChewReminder is a valid system to improve consciousness of eating activity especially chewing activity.

1 INTRODUCTION

According to the World Health Organization (WHO), overweight means BMI 25 or more and obesity means BMI 30 or more. In 2016, 39% of those aged 18 years or older were overweight and 13% of them were obese. Also, obese people are increasing about three times since 1975(Obe,). Obesity may cause lifestyle diseases such as diabetes and high blood pressure.

Chewing well induces more saliva secretion and faster blood-sugar level increase. As a result, it works on the satiety center and hungry feeling is satisfied. That leads prevention of obesity(che,). Also, Figure 1 shows that the quicker one eats, the higher BMI is(Ando et al., 2008). It means that obesity is strongly related to eating quickly. Therefore, eating slowly and chewing well is essential to prevent obesity.

Furthermore,Past studies revealed that conversation during the meal is related to health. So, increasing conversation during the meal is desirable. (Kishida and Kamimura, 1993).

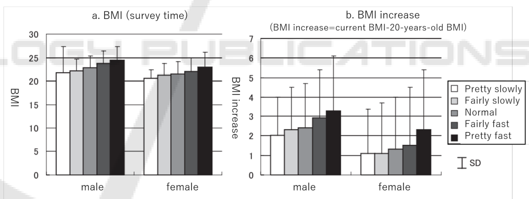

Figure 1: The relationship between BMI and BMI increase rate with eating speed (quoted from(Ando et al., 2008)).

Recently, many wearable devices available on the market. However, none of these devices can detect automatically dietary behavior, especially multiple dietary behavior such as swallowing and talking in addition to chewing in a natural meal environment yet.

If the number of chewing during the meal can be detected, it become possible to give feedback to people in real-time that they do not chew enough or eat too quickly, leading to prevent obesity. Also, it can be expected that detecting a conversation during meals can be used to make feedback promoting the increase of conversation during the meal. The detection of more specific eating behavior can contribute to the promotion of healthier dietary habits.

[a] https://orcid.org/0000-0002-9269-1026
[b] https://orcid.org/0000-0002-4802-834X
[c] https://orcid.org/0000-0003-2657-4961
[d] https://orcid.org/0000-0002-9144-3688

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2 RELATED RESEARCH

Mitsui et al. suggested a system that judges the number of chewing and the status of speaking in real-time by using a bone conduction microphone and gives real-time feedback to the user to improve his/her eating behavior(Mitsui et al., 2018). They could count in real-time chewing behavior with 91% accuracy and utterance length with 96% accuracy. However, they did not evaluate the performances in the natural meal environment yet, and the only used specific foods.

Nakaoka et al. developed a system "eat2pic" that encourages users to eat healthier by sensing what they eat using a chopstick IoT equipped with a camera and IMU sensors, and dynamically changing digital artwork based on this information.(Nakaoka et al., 2021).

However special devices are needed. The feedback system using a smartphone need to look a display during the meal. Beside, almost all systems have not detected speaking in addition to chewing and swallowing for feedback in real-time under a natural meal environment.

From above, this research aims to the feedback of specific dietary intake behavior in a natural meal environment based on the detection eating activity in real-time. Therefore, it develop and suggest feedback system including real-time feedback with a smartwatch from audio data by using a commercially and readily available bone conduction microphone placed inside the ear.

3 PROPOSED SYSTEM: ChewReminder

3.1 System Overview

The overall of "ChewReminder" is shown in Figure2. The user put a bone conduction microphone into the ear and wear a smartwatch on the wrist during a meal. The eating sound is collected using a bone conduction microphone that communicates via Bluetooth with the smartphone. Next, the section of eating activity is segmented automatically in real-time and predicted type of activity using classification model. The predicted activity leads some information about the meal such as meal time and chewing count. These information is used as feedback. The feedback is performed by two types: real-time and after the meal.

The expert said that doing feedback immediately after the action is effective. Therefore, a smartwatch is used to feedback in real-time to give a feedback immediately after the action. The smartphone is used to

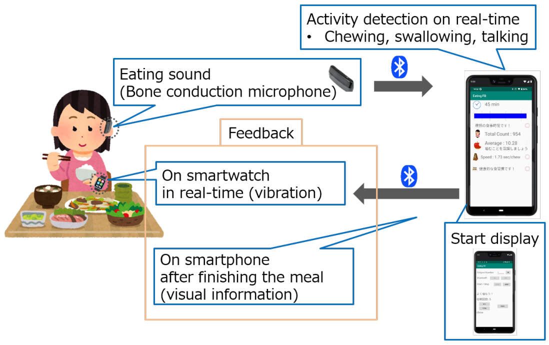

Figure 2: The system overview.

feedback whole meal information after meal because that a smartphone can display a lot of information.

The smartphone used was a Google Pixel 3 and 3a (produced by Google co. Ltd.), the bone conduction microphone was a MOTOROLA Finiti HZ800 Bluetooth Headset (produced by Motorola co. Ltd.), and the smartwatch was a POLAR M600 (produced by POLAR). The sound signal sampling from the microphone was 8kHz.

3.2 Algorithm of Eating Activity Detection

3.2.1 Classification Model

The machine learning was used to build models that can classify chewing, swallowing, speaking, and other sounds. The classification model with Random Forest using 31 extracted features suggested by Kondo et al. was selected to implement the Android app feedback system.(Kondo et al., 2021).

3.2.2 Method of Segmentation

The eating activity was detected by the Android app implemented algorithm of detection eating activity using dietary sound collected by a bone conduction microphone. This algorithm segmented audio data automatically corresponding to the detailed eating activity suggested by Kamachi et al. (Kamachi et al., 2021).

3.3 Feedback System

3.3.1 Eating Activity Detection App

The proposed feedback system in this research (ChewReminder) consists of an Android app using both a smartphone and a smartwatch. The smartphone app detects four eating activities: chewing, swallowing, speaking, and others. First, the user connects a bone conduction microphone to a smartphone via

Bluetooth. Next, after he/she taps Bluetooth ON button, he/she can start the system.

The bone conduction sound is automatically segmented by segmentation method described in 3.2.2. After segmentation, the features are extracted and eating activity is predicted using implemented classification model by method described in 3.2.1. The classification model implemented in the app was built using Weka(wek,), which is a machine learning software. In this research, chewing and bite are defined as following.

- Chew/Chewing: the action/activity of masticating food between teeth once.
- Bite: the process composed of several chews from putting food into the mouth to swallowing it.

3.3.2 Feedback Content

The smartphone app measures following information in real-time. These information are used to do feedback. Also, the app records the each detection time, detection activity, the number of bite and the each chewing count per bite in csv file.

- The total meal time between app start when tapping START button to stop when tapping STOP button
- The total chewing count in the meal
- The chewing count per one bite and calculate average chewing count per bite from all chewing count per bite
- The chewing pace as average time per one chewing (seconds / chewing) calculated using time of one bite and chewing count per bite
- The total talking time by summarizing time of detection speaking
- The total eating time of chewing calculated by summarizing each time of one bite

The feedback system is consist of two types. These are real-time feedback using a smartwatch and visual feedback using a smartphone after the meal.

3.3.3 Real-Time Feedback on Smartwatch

The real-time feedback on a smartwatch uses a vibration depend on chewing count per one bite to do natural meal preventing looking a visual feedback all time like a display of smartphone during the meal. The smartwatch vibrates long when swallowing is detected if chewing count per bite is less than 20. Also, the smartwatch vibrates short when chewing count per bite achieve 20 to tell user about reaching the standard value. The standard count per bite is set 20 because that modern people chew from 10 to 20 times per one bite(ave,).

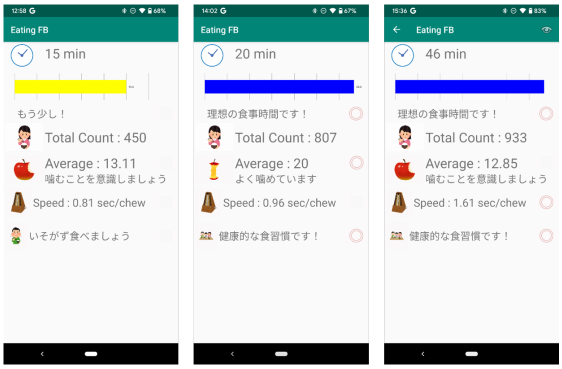

Figure 3: Screenshots of feedback display examples.

3.3.4 Feedback on Smartphone

The smartphone app display feedback of whole meal after finishing the meal as taping the STOP button. The item of feedback is the total meal time, total chewing count, average of chewing count per bite, average of chewing pace, rate of eating time and rate of talking time. Figure 3 shows an examples of smartphone feedback display.

The feedback display was used an icon, bar chart, text of number value and text sentence of advise to understand easily. The each item has a standard value and shows a double circle if the each value exceed the standard value. The standard value of total meal time is 20 minute because of from 15 to 20 minute is the ideal meal time(mea,). The feedback of meal time changed bar chart color and advice message depend on three steps: less than 15, between from 15 to 20 and 20 or more. The standard value of average chewing count per bite is 20. The reason why is described in 3.3.3. An icon of apple and advice message are changed depend on three steps: less than 10, between from 10 to 20 and 20 or more. The standard value of chewing pace and last item was determined by data collected from four people during the meal. From these result and environment of meal, the standard value of chewing pace is 1.0 second per one chewing. The last item of feedback is based on talking rate and eating rate. The good meal have 20% or more eating rate calculated by eating time and total meal time from above result. Also, this research defined that good meal include 10% or more talking rate calculated by detection speaking time and total mealtime. The icon and advice message is changed depend on three steps: condition of good meal, condition of bad meal and other.

4 EVALUATION EXPERIMENT

The real-time feedback experiment was performed to evaluate verification of effectiveness real-time feedback with smartwatch. Also, long-term experiment was performed to evaluate verification of effectiveness feedback displayed on a smartphone.

4.1 Overview of the Experiment

This experiment was performed to verify if proposed feedback system affect the consciousness of eating activity. The purpose of the real-time feedback experiment was investigation of changes for eating activity and consciousness especially by aspect of real-time feedback. The purpose of the long-term experiment was investigation of changes for eating activity and consciousness especially by aspect of displayed feedback.

4.2 Experimental Method

4.2.1 Real-Time Feedback Experiment Method

Data from 14 men and women aged from 21 to 26 years old were collected. Two or three subjects were participating together at the same time because they were required not only eating but also talking to each other during the meal. The subjects were required to eat twice a lunch box on different days. Once with real-time feedback on a smartwatch, and the other time without real-time feedback.

The subjects wore an in-ear bone conduction microphone and a smartwatch in both experiment.

Before the experiment, subjects answered five grade evaluation of the questionnaire items to confirm the result for people who has consciousness of eating fast.

The subject experimented case with real-time feedback was required to be conscious of chewing count per bite based on vibration feedback types. After experiment case with real-time feedback, subjects answered the questionnaire about ChewReminder. Figure 4 shows the experiment environment. The all experiment was performed around lunch time.

The following indices were chosen for evaluation: total meal time, total chewing count, average of chewing count per bite and chewing pace displayed in final feedback on a smartphone. These values are compared between case with real-time feedback and non real-time feedback.

The evaluation result is good when these values is increased. The better eating habit, the longer the meal time at least 20 minute. The many chewing count is

Figure 4: Snapshot of the data collection environment.

good for healthy meal. Also, chewing count per bite need increase for good meal. The chewing slowly is good to prevent obesity, so bigger value of chewing pace is good to eat.

Also, subjects answered the questionnaire about this feedback system and ChewReminder after experiment case with real-time feedback.

4.2.2 Long-Term Experiment Method

This experiment was performed to verify if ChewReminder affects the eating activity especially aspect of displayed feedback on a smartphone.

Data from three women (subject 1, 2 and 3) aged from 21 to 42 years old were collected. They used ChewReminder consecutively around a week during the meal regardless of type of meal like lunch and dinner.

- Subject 1 used this system without real-time feedback on a smartwatch for a week (seven days) during almost every meal. The total data is 19.
- Subject 2 used this system with real-time feedback on a smartwatch for four days during lunch and dinner with her family. The total data is six.
- Subject 3 used this system with real-time feedback on a smartwatch for five days during lunch and dinner eaten alone. The total data is seven.

Subjects answered the questionnaire same as real-time feedback experiment before start the data collection and after the all data collection.

5 EVALUATION RESULTS

5.1 Real-Time Feedback Experiment

5.1.1 The Total Meal Time

The number of people who the total meal time was longer value obtained with real-time feedback than that without real-time feedback was six out of total 14. Figure 11 shows the result of all subjects.

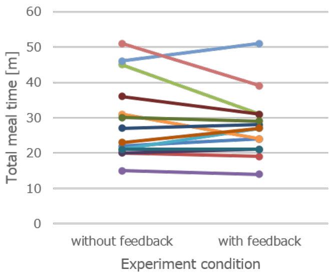

Figure 5: Total meal time per subject regardless the order of the experiments.

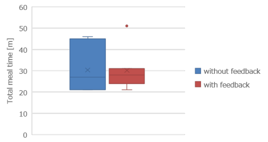

Figure 6: Average total meal time when the first meal was using real-time feedback.

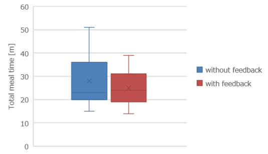

Figure 7: Average total meal time when the first meal was without feedback.

The box plot of the result are showed in following figure. Figure 6 shows the result of case with real-time feedback at first and Figure 7 shows the result of case without real-time feedback at first. The box plot result shows that the mean and median value when the meal was using feedback increased compared to the value of non real-time feedback in group that experimented using real-time feedback at first. Also, the median value when the meal was using real-time feedback is increased compared to value when the meal was without real-time feedback in the group that experimented without feedback at first.

The following figure shows the result of total meal time per subject. Figure 8 shows the result of case with real-time feedback at first and Figure 9 shows the result of case without real-time feedback at first. The four out of seven people improved the value of total meal time from obtained without real-time feedback to obtained using real-time feedback in the group that experimented firstly using real-time feedback. The almost all people is over the standard time as 20 minute. The total meal time of less than half people for others was shorter or not changed. The reason why less than half of the participants increased their meal time may be that environment was different during the two meals: difference the rate of talking and eating pace depend on number of people who eat together.

5.1.2 The Total Chewing Count

The number of people who increased the total chewing count data with real-time feedback from data without real-time feedback was nine out of total 14.

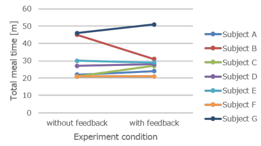

Figure 8: Total meal time per subject when the first meal was using real-time feedback.

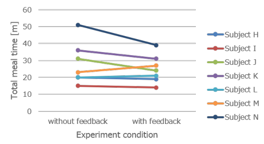

Figure 9: Total meal time per subject when the first meal was without feedback.

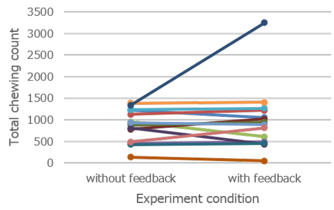

Figure 10: Total chewing count per subject regardless the order of the experiments.

Figure 10 shows the result of all subjects.

The box plot of the result are showed in following figure. Figure 12 shows the result of case with real-time feedback at first and Figure 13 shows that the result of case without real-time feedback at first. The box plot result shows that the mean value when the meal was using real-time feedback increased compared to the value when the meal was without real-time feedback in both group. It was confirmed that chewing count can be improved by using ChewReminder.

The following figure shows the result of total chewing count per subject. Figure 14 shows the result of case with real-time feedback at first and Figure 15 shows the result of case without real-time feedback at first. The four out of seven people improved the value of total chewing count from obtained without real-time feedback to obtained using real-time feedback in the group that experimented firstly using real-time feedback. The more than half of participants (four out of six) who answered agree or strongly agree to the questionnaire before experiment items of “Do you think you eat fast (eating fast)?” increased total chewing count.

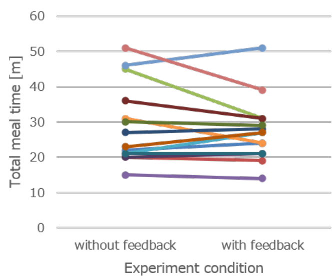

Figure 11: Total meal time per subject regardless the order of the experiments.

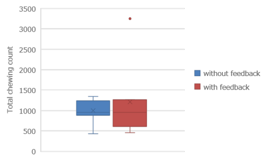

Figure 12: Average total chewing count when the first meal was using real-time feedback.

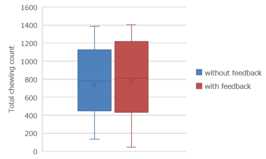

Figure 13: Average total chewing count when the first meal was without feedback.

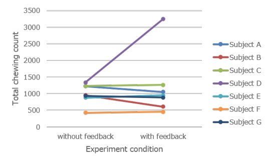

Figure 14: Total chewing count per subject when the first meal was using real-time feedback.

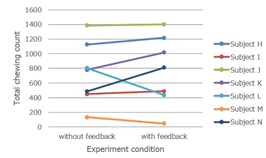

Figure 15: Total chewing count per subject when the first meal was without feedback.

5.1.3 The Average Chewing Count

The number of people who increased the average of chewing count per bite with real-time feedback from data without real-time feedback was 10 out of total 14 which is over than 70%. Figure 16 shows the result of all subjects.

The box plot of the result are showed in following figure. Figure 17 shows the result of case with real-time feedback at first and Figure 18 shows the result of case without real-time feedback at first. The box plot result shows that the mean and median value when the meal was using real-time feedback increased compared to the values of non real-time feedback in both group. It was confirmed that chewing count per bite can be improved by using ChewReminder.

Four out of seven people who used ChewReminder first and six out of seven who used it last had higher average chewing count per bite when using ChewReminder real-time feedback. Almost all the participants (five out of six) who answered agree or strongly agree to the questionnaire before experiment items of “Do you think you eat fast (eating fast)?” increased their average chewing count per bite.

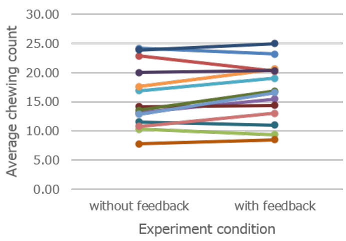

Figure 16: Average chewing count per subject regardless the order of the experiments.

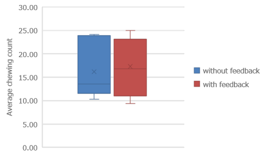

Figure 17: Average chewing count when the first meal was using real-time feedback.

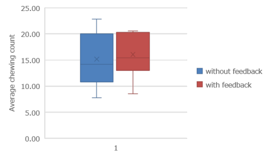

Figure 18: Average chewing count when the first meal was without feedback.

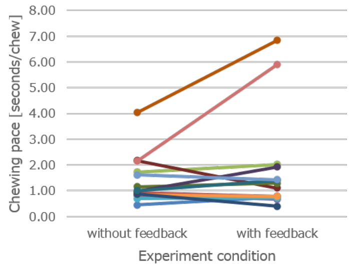

Figure 19: Chewing pace per subject regardless the order of the experiments.

5.1.4 The Eating Pace

The number of people who increased the chewing pace with real-time feedback from data without real-time feedback was eight out of total 14 which is over than half. Figure 19 shows the result of all subjects.

The box plot of the result are showed in following figure. Figure 20 shows the result of case with real-time feedback at first and Figure 21 shows the result of case without real-time feedback at first. The box plot result shows that the mean and median value when the meal was using real-time feedback increased compared to the values of non real-time feedback in both group. It was confirmed that chewing pace can be improved by using ChewReminder.

The following figure shows the result of chewing pace per subject. Figure 22 shows the result of case with real-time feedback at first and Figure 23 shows the result of case without real-time feedback at first. Five out of seven people improved the value of chewing pace from obtained without real-time feedback to obtained using real-time feedback in the group that experimented firstly using real-time feedback. The three out of seven people improved the value of chew-

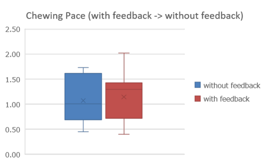

Figure 20: Chewing pace when the first meal was using real-time feedback.

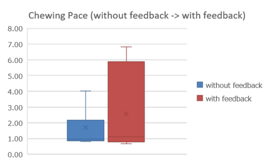

Figure 21: Chewing pace when the first meal was without feedback.

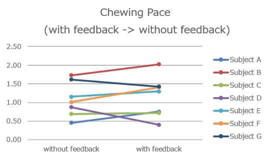

Figure 22: Chewing pace per subject when the first meal was using real-time feedback.

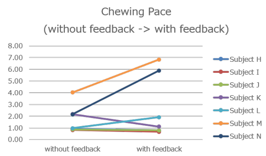

Figure 23: Chewing pace per subject when the first meal was without feedback.

ing pace from obtained without real-time feedback to obtained using real-time feedback in the group that experimented firstly without real-time feedback. There are no significant difference. The almost all participants (five out of six) who answered agree or strongly agree to the questionnaire before experiment items of "Do you think you eat fast (eating fast)?" increased chewing pace. The difference of chewing pace between case with real-time feedback and without real-time feedback for other participants who did not increase the value was from 0.1 to 1.0 seconds per one chewing.

5.1.5 The Questionnaire

The average of the System Usability Scale was 83.6. It is significantly above the average score of SUS, which is 68. The SUS score of 13 out of 14 people is over the average score. It indicates the usability of ChewReminder. Also, More than half of the people in the questionnaire showed an increase in consciousness of chewing and talking compared to their answers in the questionnaires.It indicates the effectiveness of ChewReminder in improving the consciousness of eating behavior.

5.2 Long-Term Experiment

Figure 24 and figure 25 shows the changes in the average chewing count per bite and the chewing pace for subject 1. From subject 1, all results are over 20, a commonly used reference value of sufficient chewing count per bite. Subject 1 did not use real-time feedback on a smartwatch. This result indicates that the displayed feedback on the smartphone is sufficient to maintain a good eating habit of chewing well, such as chewing over 20 bites.The chewing pace increased from the first time to the last time. Although every meal is different, the chewing pace has a rising trend. It indicates the possibility that ChewReminder improves the eating pace by using it.

Figure 26 and figure 27 shows the changes in the average chewing count per bite and the chewing pace for subject 2. From result of subject 2, chewing count per bite is decreasing trend at first, last three data is

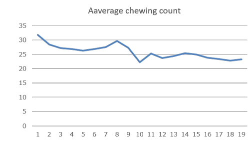

Figure 24: Average chewing count of subject 1.

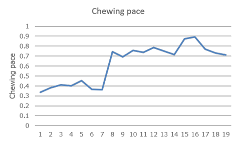

Figure 25: Chewing pace of subject 1.

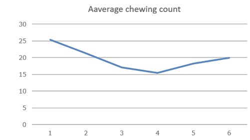

Figure 26: Average chewing count of subject 2.

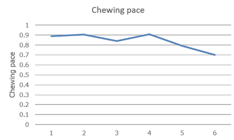

Figure 27: Chewing pace of subject 2.

increasing. The 5th data was obtained after pause of few days, so it is considering that the average chewing count per bite was decreased.Chewing pace is increasing trend in first half. It is also considering that the pause of few days caused decreasing of chewing pace.

Figure 28 and figure 29 shows the changes in the average chewing count per bite and the chewing pace for subject 3. From result of subject 3, average of chewing count per bite is rising trend for all data. This result indicate that the ChewReminder using real-time feedback and displayed feedback after the meal can improve chewing count per bite. Chewing pace is not rising trend for all data. The decreased data is meal of noodle.

The participants of this long-term experiment answered the questionnaire. SUS score of subject 1 was 67.5, subject 2 was 70.0 and subject 3 was 87.5. The average of their result was 75.0. It indicate the usability of ChewReminder.

Figure 30 shows the result of questionnaire of positive aspect which is good when selecting strongly agree. Figure 31 shows the result of questionnaire of negative aspect which is good when selecting strongly disagree. The result of questionnaire shows that only one people was conscious of talking and eating slowly during the meal by using ChewReminder. More than half people answered agree or strongly agree to the other items of questionnaire. From these, it is revealed that ChewReminder improved the consciousness of eating activity during a meal and chewing. Also, two people answered a higher number in the five

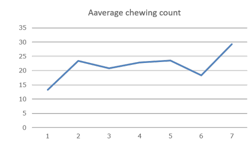

Figure 28: Average chewing count of subject 3.

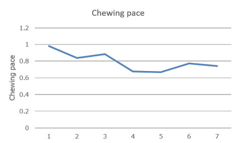

Figure 29: Chewing pace of subject 3.

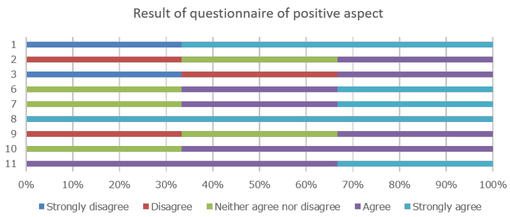

Figure 30: Result of questionnaire of positive aspect.

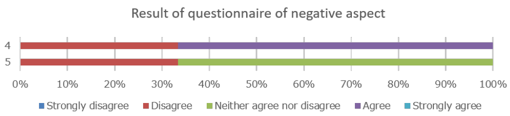

Figure 31: Result of questionnaire of negative aspect.

grade evaluation to the questionnaire items about conscious of chewing in the meal compared to conscious of chewing to the answer of questionnaire before the experiment, indicating effect especially conscious of chewing activity by using the ChewReminder.

6 CONCLUSIONS

This research proposed ChewReminder which is a feedback system using dietary sound by real-time feedback on a smartwatch and displayed feedback on a smartphone to improve eating habit. The Android app on a smartphone detect eating activities by three steps: segmentation dietary sound, extraction features and prediction using a classification model. The smartwatch gives feedback using vibration depend on chewing count per one bite which information was linked from the smartphone. Also, the total feedback about the meal was displayed on the smartphone after finishing the meal.

The objectives of this research was achieved. ChewReminder can detect eating activity in real-time under a natural meal environment and provide feedback based on detected eating activity. The chewing count for 70% subjects and chewing pace for more than half subjects was improved with using ChewReminder by the result of total chewing count, average of chewing count per bite and chewing pace. The proposed system chewReminder is effective especially people who are aware of fast eating. Also, the result of long-term experiment indicated that feedback displayed on a smartphone was effective to improve consciousness of eating activity. Therefore, the result of both experiment shows that ChewReminder is a valid system to improve consciousness of eating activity especially chewing activity.

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