A PRESSURE SENSITIVE PALATOGRAPHY: APPLICATION OF NEW PRESSURE SENSITIVE SHEET FOR MEASURING TONGUE-PALATAL CONTACT PRESSURE

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ABSTRACT

This paper describes a new method for measuring the tongue-palatal contact pressure using a thin pressure sensor and its application for speech research. The new pressure sensor is composed of thin pressure sensitive ink whose electrical resistance is proportional to the physical forces applied to the sensor. Several sensors were arranged on the surface of the palatal plate. This setup was used to measure the tongue pressure toward the hard palate during closure for Japanese stop consonants [t] and [d]. Results obtained from 10 Japanese subjects showed the tongue-palatal contact pressure for [t] to be stronger than that for [d]. In addition, the sensors placed on the non-contact area showed no pressure change, indicating negligible effects of intra-oral air pressure during consonantal closure.

1. INTRODUCTION

Tongue-palatal contact is a critical articulatory gesture in producing many speech sounds, and it has been measured using the electropalatography (EPG) system. EPG was developed to visualize dynamic articulatory events of tongue-palatal contact through an array of electrodes placed on an individually designed artificial palate. This system detects the area where the contact occurs and records its dynamic changes, but not the tongue-palatal pressure distribution applied on the surface.

Attempts have been made to measure the tongue-palatal contact pressure experimentarily using miniature strain gauge sensors on an artificial palate [1]. However, several problems were noted in this system, such as the size and thickness of the device, and the presence of artifacts due to an intra-oral air pressure.

The aim of the present paper is to develop a new method for measuring realistic tongue-palatal contact pressure values, with no interference of the device on articulation nor artifacts due to intra-oral air pressure. To do so, the new high-sensitive pressure sensor sheets were developed. This report also documents results from preliminary experiments using Japanese stop consonants obtained from ten subjects, and discusses possible applications of this method.

2. METHOD

2.1 Structure of the Sensor Sheet and Measurement Mechanism

Figure 1 shows the structure of a sensor sheet. The principle behind monitoring the contact pressure is to sense a change in the distance between a pair of thin sheet electrodes by measuring the electrical resistance of the “pressure sensitive ink” between the two electrodes [2]. A sensor electrode is 3 mm in diameter, and it has a sensitivity of 173 to 2734 Pa (approximately 0.005 to 0.3 kg/cm^2) with less than 10 % error. The pressure sensor array sheet is composed of two, three, or four sensors and sealed by polyester sheets with a certain amount of air. The local thickness of the sensor sheet is approximately 0.1 mm.

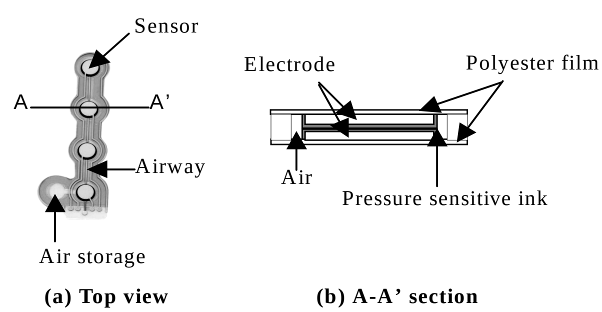

Figure 1: Structure of a sensor sheet.

2.2. Arrangement of Sensor Sheet on Palatal Plate

Figure 2 shows an example of a pressure sensor array sheet arrangement. A personal acrylic palatal plate was prepared based on a full plaster impression of the speaker's palate and teeth. Using conventional dental procedures, the impression was carefully made so that it covered the posterior edge of the hard palate. The palatal plate was offered so as not to interfere with normal speech production and to be robust enough to maintain its shape accurately. To satisfy these conditions, the palatal plate was made to be about 0.5 mm thick. The posterior end of the palatal plate was rested at the juncture between the hard and soft palates. Retention clasps constructed by stainless steel wire were placed on the canines and first molars.

The sensor sheets were attached on the surface of the palatal plate with non-toxic adhesive. The number and layout of the sensor sheets were adjusted for the individual palatal shape. In all cases, the central sensor array sheet position was adjusted on the midsagittal line of the palate, and its front-end electrode was placed on the incisive papilla (a small gingival ridge located just backside of the central incisors). The lateral sensor sheets were usually placed along the dental arch. All acquired pressure data was transferred by enameled copper wires that connected each of the pressure sensors up to the sensor controller. The copper wires from the sensor sheets ran along the furthest corner of the dental arch to avoid interfering with the occlusion. In the example of Figure 2, sixteen pressure sensors are arranged on the palatal plate.

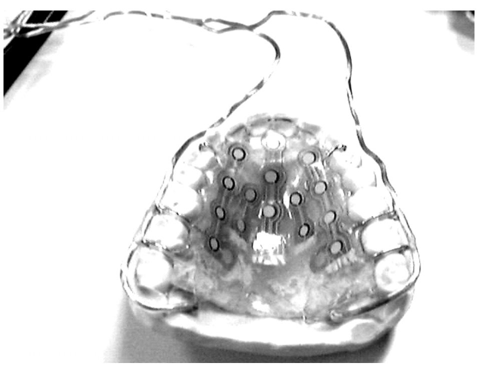

Figure 2: An example of sensor sheets arrangement.

2.3. Experiment

A preliminary experiment was conducted to test the performance of the pressure sensors. The Japanese alveolar stops [t] and [d] were chosen because they show similar contact patterns, and it is difficult to distinguish one from the other only by usual EPG analysis.

The subjects were 10 native Japanese speakers (6 males and 4 females; age: 23-48) with no articulation disorders. The age and sex of each of the subjects and the number of sensors placed on his/her palate were shown in Table1.

Speaker (Sex)	Age	No. of sensors.
KH (M)	48	16
SM (M)	43	12
NK (M)	33	16
KT (M)	32	16
YD (F)	30	9
AC (F)	30	9
RK (F)	26	11
KO (M)	26	16
YM (M)	25	16
KA (F)	23	9

Table 1: Subject details.

2.3.1. Experimental setup

Figure 3 shows a schematic diagram of the experimental setup. Pressure sensors were put on the palatal plate in the subject's mouth. The tongue-palatal contact pressure data was recorded by the sensor controller (Sampling frequency: 126 Hz). Speech sounds by the subject were also recorded by a multi-channel data recorder (PC-216A, SONY Precision Inc. Japan, Sampling frequency: 24 kHz/Ch.). For synchronous analysis, the data recorder also recorded the frame timing pulse generated from the pressure sensor controller.

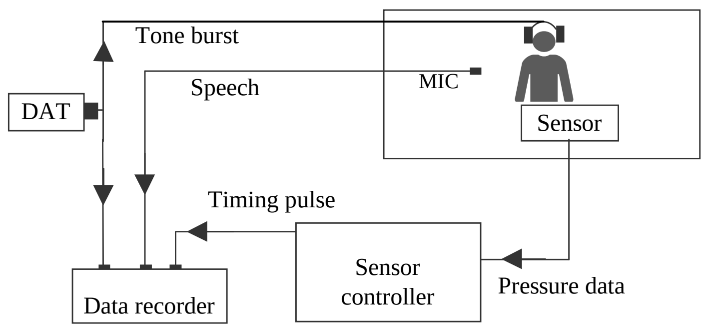

Figure 3: System diagram.

2.3.2. Procedure

Two tone burst signals (1 kHz sine wave with a 100 ms duration with a 500msec separation) were presented to the subject through headphones (see figure 3). The subjects produced [ata], or [ada], to synchronize each mora with every tone burst. Each target word was repeated five times.

After the experiment, the recorded pressure data and speech sounds were stored as a set of a file with reference to the timing pulse.

3. RESULTS AND DISCUSSION

An example of acquired data from subject YM for [ata] production is shown in Figure 4. In this figure, the top panel shows the speech signal, and the bottom panel shows the time function of the pressure data obtained during the production of [ata].

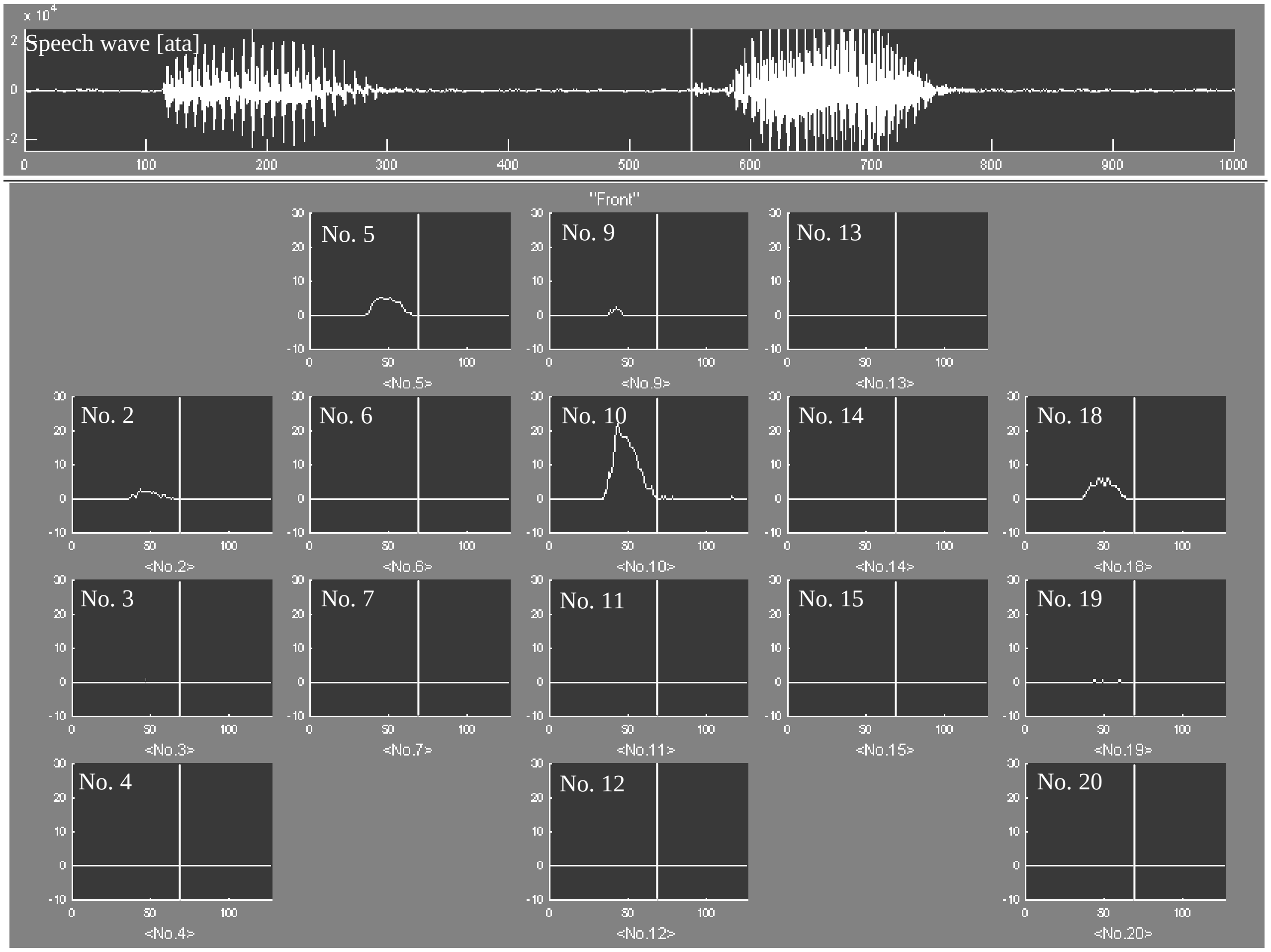

Figure 4: Speech wave and time function of the pressure for [ata] (subject YM). Each number corresponding to the sensor's ID is shown in Figure 5.

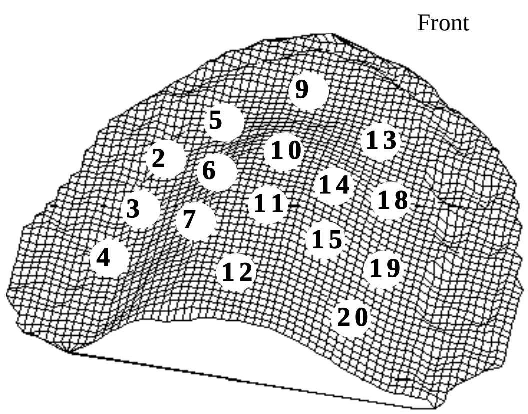

Figure 5: Sensor locations on the palatal plate (subject YM). Sensor No. 9 is located on the Incisive Papilla.

For this subject, the number of arranged pressure sensors was 16. The locations of the sensors are shown in Figure 5.

In this study, the results of the experiments were investigated from the following points of view.

1. Effect of the intra-oral air pressure on the output of the new pressure sensor.
2. Difference in the tongue contact pressure during the stop periods of [t] and [d].

3.1. Influence of Intra-oral Air Pressure

For the structure of each pressure sensor, pressure sensitive ink is printed on two sheet electrodes, and these sheet electrodes are piled so as to face the printed ink. If no pressure is applied, there is a certain space between the electrodes owing to the internally sealed air. Between sensors the internally sealed air is connected by an airway. Therefore, when a uniform pressure is applied on all of the pressure sensors in the same sensor array sheet, a small space is maintained between the electrodes resulting in no output for the sensors.

According to the output time function such that displayed in Figure 4, the sensors arranged in the non-contact area for [ata] (such as Nos. 7, 11, 12, and 15 in Figure 5) do not show any changes in the pressure during the production. This result suggests that these sensors distinguish the tongue-palatal contact pressure from the intra-oral air pressure.

3.2. Difference in the Tongue-palatal Contact Pressure due to Voiced vs. Unvoiced Discriminations

[t] and [d] are unvoiced and voiced stops, respectively, having a similar place of articulation. During the stop period of voiceless stop [t], the vocal folds are abducted, and the intra-oral air pressure reaches the lung pressure (anticipating the burst after the release). On the other hand, in the stop period of [d], vocal fold vibration maintains and the air pressure is smaller in the oral cavity than in the lung [3]. For this reason, the intra-oral air pressure for [t] production is expected to be higher than that of [d]. To maintain the oral air pressure during the stop period, the tongue-palatal contact pressure for [t] should be higher than that for [d].

The time functions of the pressure for [ata] and [ada] at sensor 9 for subject YM (averaged for three of five repetitions) are shown in Figure 6. The maximum contact pressure for [t] is higher than that of [d]. This tendency was consistent for all of the subjects.

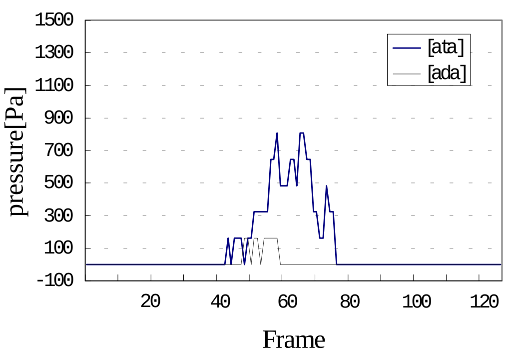

Figure 6: Time functions of the pressure for sensor No. 9. (subject YM).

3.3. Discussion

The new pressure sensitive sheet was designed for monitoring the tongue-palatal contact pressure. According to the results, the sensors did not sense intra-oral air pressure change. Therefore, this device has a good performance for the speech production study.

From results on investigating the tongue-palatal contact pressure difference between [t] and [d], the maximum pressure for [t] production was higher than that of [d]. This result shows the possibility that the sensor's sensitivity should be sufficient for device application in speech production studies and to some other clinical purposes.

4. SUMMARY

This report described a new method for measuring the tongue-palatal contact pressure using a thin pressure sensitive sensor array sheet that detects the local contact pressure. The characteristics and advantages of this method can be summarized as follows.

1. The new thin pressure sensor array sheet was developed for monitoring the tongue-palatal contact pressure.

2. The new pressure sensor sheet designed in this study can sense realistic tongue-palatal contact pressure values without the interference of the intra-oral air pressure.

3. This method is capable of demonstrating differences in the strength of the tongue-palatal contact pressure among various consonants. In preliminary experiments, the difference in the maximum contact pressure during the stops between [t] and [d] was shown plausibly.

4. The results of the preliminary experiments also suggested the possibility of applying this system to speech production studies and to some other clinical purposes.

5. ACKNOWLEDGMENT

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6. REFERENCES

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