Reliability of electromagnetic midsagittal articulometry and electropalatography data acquired simultaneously

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This study evaluates the effects on electromagnetic midsagittal articulometry (EMA) coils from electrode activation on an electropalatography (EPG) artificial palate, and on EPG contact patterns induced by EMA coils. In order to investigate the first issue, five transducer coils on a fixed magazine were placed equidistantly among themselves and with respect to the three transmitter coils of an EMA helmet. Two palate positions were used, i.e., perpendicular to the magazine (to emulate possible effects on coils placed on the nose, upper incisors, jaw, and lips) and parallel to it (to imitate effects on coils placed on the tongue surface). A thin leaf of aluminum firmly pressed by a mold was used to create contact activation. Data for different degrees of contact activation were subtracted from data obtained with no artificial palate (perpendicular condition) or with an artificial palate with zero ''on'' electrodes (parallel condition). Only for the most extreme condition, i.e., a high degree of contact activation and a short coil-to-artificial palate distance, do the effects slightly exceed the noise level for the EMA equipment. The analysis of the second issue was carried out for coils attached to the tongue tip, the tongue blade, and the tongue dorsum during the production of several consonants. Coil-to-lingual contact effects occur mostly near the midline of the artificial palate at different locations, depending on the degree of contact and the location of the consonant.

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INTRODUCTION

The main goal of this study is to evaluate possible effects on the measured location of transducer coils of an electromagnetic midsagittal articulometry (EMA) system caused by electrode activation on an artificial palate of an electropalatographic (EPG) system.

EMA transduces horizontal and vertical tongue movements. Coil-to-palate distance can be derived from palate tracings obtained by moving a coil along the hard palate. EPG provides linguopalatal contact patterns over the sagittal and coronal dimensions. It is thus the case that, while EMA and EPG give information about the front–back dimension, only the former technique provides data on the vertical component and only the latter technique provides data on the coronal component. Therefore, the simultaneous use of these two techniques has obvious advantages for analyzing lingual activity.

Hoole (1993) measured possible differences in EMA calibration values obtained with and without EPG. He found the average error to be about 0.3 mm in the EPG versus non-EPG condition; however, no details on the measurement procedure are given and it is not certain if the differences were due to the EPG equipment or to differences in coil position. The present study makes sure that the coil position is always fixed and takes into consideration variables such as linguopalatal contact size and palate-to-coil orientation in order to emulate a real speech production setting. Although the interferences in measured coil location caused by different EPG contact conditions refer to a static experimental scenario in the present paper, they can be extended to a dynamic situation where coils are attached to the speaker's articulators.

A second goal of this investigation is to find out whether linguopalatal contact is affected by the use of EMA coils placed on the tongue surface. No information about this aspect is reported in studies where the two techniques have been used simultaneously (Hoole, 1993; Kühnert, 1993). Considering that coils are placed near the tongue midline, contact between palate and EMA coils rather than contact between palate and tongue tissue could affect electrode activation near the midline of the artificial palate.

I. METHOD

The magnetometer used in this work is the AG100 system from Carstens Medizinelektronik, Göttingen. The EMA system (Schönle *et al.*, 1987; Schönle, 1988) contains three transmitter coils held in a helmet with the coil axes perpendicular to the midsagittal plane. Small transducer coils are attached to the speaker's articulators (e.g., tongue tip, tongue dorsum, lips, mandible) as close as possible to the midline; reference coils are also positioned on the nose and the upper incisors for head movement correction. The alternating magnetic fields generated by the transmitters induce alternating voltages in the transducers as the articulators move during the production of speech. The voltages are then converted to distance signals for analysis of articulatory movements.

The Reading EPG system (Hardcastle *et al.*, 1989) was used for the linguopalatal contact recordings. The artificial palates are equipped with 62 electrodes arranged in coronal rows and sagittal columns (shown in the upper left diagram in Fig. 2). The electrodes are activated as the tongue touches the palate. The four front rows belong to the alveolar zone and the four back rows to the palatal zone. The artificial palate for the speaker for whom the EPG and the EMA data were collected has a much shorter distance between adjacent rows in the four front rows versus the four back ones: 2.7 mm (between rows 1 and 2, 2 and 3, and 3 and 4), 6 mm

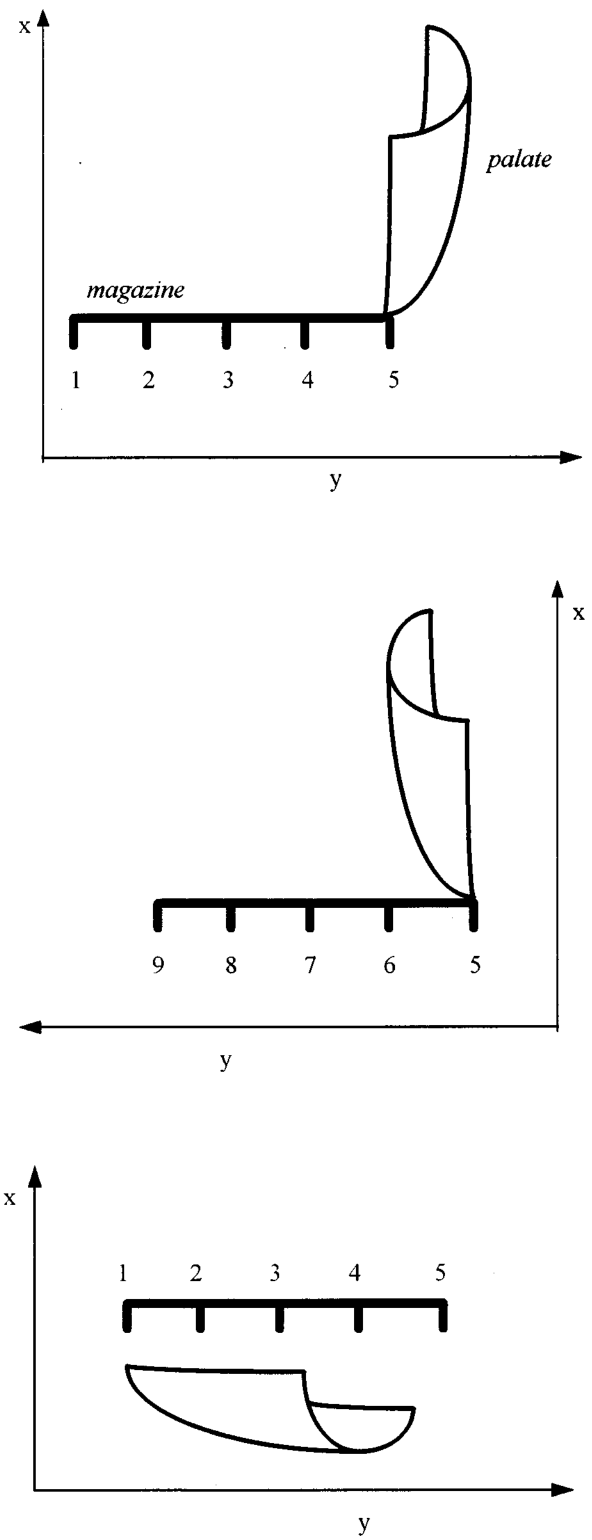

FIG. 1. Conditions of palate placement with respect to a magazine with five coils attached to it. In the perpendicular condition, the palate is placed on coil 5 so that the coils numbered 1–4 are in front of it (top graph) and those numbered 6–9 are behind it (middle graph); in order to achieve the latter configuration the artificial palate is rotated 180° so that electrodes 1–4 become 9–6. In the parallel position (bottom graph), the palate is facing coils 1–4. The orientation of the *x* and *y* axes is imposed by the EMA system software.

(between rows 4 and 5), 8 mm (between rows 5 and 6), 9 mm (between rows 6 and 7), and 8.5 mm (between rows 7 and 8). These distances are important in order to interpret the interference patterns described in Sec. II B.

First, the calibration of the transducers of the EMA system was performed using the AG100 MKal 64 program. For that purpose, five SM220-80B coils whose diameter was 2 mm long were positioned equidistantly on a fixed magazine located at the center of the measuring area of the EMA helmet (intercoil distance=1 cm).

After calibration, an artificial palate was placed perpendicularly and horizontally to the fixed magazine for measuring possible distortions on coil location. This experimental setup ensures that transducers show little rotational misalignment, i.e., that their tilt value is zero or very close to zero. The EMA signal was recorded at a nonmultiple frequency (111 Hz) of the network frequency (50 Hz) in order to avoid possible interferences between the two systems; this arbitrary sampling frequency yields a 9-ms distance between adjacent temporal frames. The experimental procedure described below was applied separately to three artificial palates so as to obtain more representative results than for a single palate alone. These artificial palates differed mostly in height (they were about 1 cm, 1.5 cm, and 2.2 cm high), and less so in length and width (they were about 4–4.5 cm long and about 3.5–4 cm wide at the back).

In the perpendicular condition, the palate was positioned on the extreme coil 5 and subject to a 180° rotation so that its top and bottom parts faced the remaining four coils on the magazine (see Fig. 1, top and middle graphs); those coils have been numbered differently in the figure depending on the experimental condition involved, i.e., 1–4 for the top palate condition and 6–9 for the bottom palate condition. In a real speech production setting, these two scenarios allow measuring the possible effects from the artificial palate on coils perpendicular to the palate surface, on the nose, upper incisors, jaw, and lips. As for the parallel position, the palate was facing the magazine along coils 1–4 (see Fig. 1, bottom graph). This scenario allows inferring possible effects on coils attached to the tongue surface from the tongue tip to the tongue back.

Different numbers of electrodes were activated at different zones of the artificial palate (see Fig. 2) with the help of a thin leaf of aluminum firmly pressed by a nonmagnetic mold.

First, one set of three 5-s sweeps was recorded with an artificial palate placed perpendicularly for each of the following activation conditions, i.e., 0 ''on'' electrodes, 22 ''on'' electrodes at the front, 40 ''on'' electrodes at the sides, and 62 ''on'' electrodes over the whole surface. This contact distribution was designed to be representative of common consonantal articulations, i.e., alveolar closure for an alveolar stop (22), central alveolopalatal constriction for a palatal fricative (40), and full alveopalatal closure for an alveolopalatal stop (62). The effects of a lateral contact configuration and of a central contact configuration with about 30 ''on'' electrodes were also measured with the palate placed perpendicularly.

The data for each EPG activation condition were obtained as follows: Two coil signal measurements without the palate and the mold were taken before and after each measurement with the artificial palate in place. The measurement values without the palate were averaged and the resulting

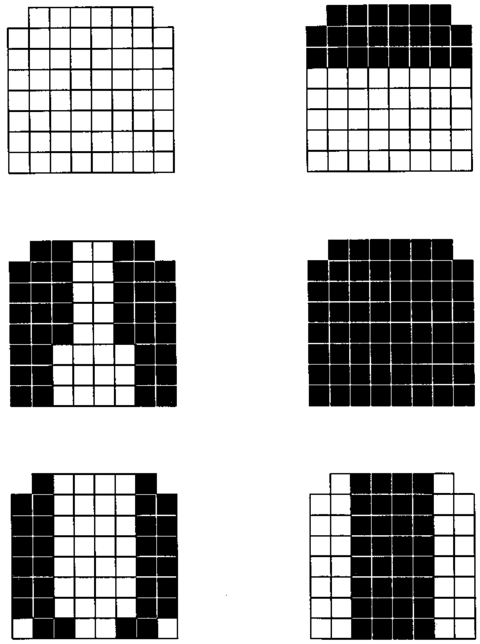

FIG. 2. Linguopalatal contact patterns used in the experiment differing in amount and distribution of electrode activation. (Top left) 0 ''on'' electrodes, (top right) 22 ''on'' electrodes as for an alveolar stop; (middle) 40 and 62 ''on'' electrodes as for a palatal fricative and for an alveolopalatal stop respectively; (bottom) 30 ''on'' electrodes at the palate sides and 32 ''on'' electrodes at the palate center.

average was subtracted from the measurement value with palate. The same operation was repeated two more times. Data for each subtraction operation were averaged across all temporal frames of each sweep and the resulting averages were averaged among themselves.

Second, two sets of three 5-s sweeps were recorded with the magazine parallel to an artificial palate with 62 activated electrodes; two distance conditions, i.e., 6–7 mm and 4–5 cm, were tested in this case. In a real speech production setting, the tongue coils touch the palate surface and thus the linguopalatal distance is smaller than 6–7 mm; this distance condition was not tested in the present experiment since a mold was needed to create contact activation on the artificial palate. It is hypothesized that the two unrealistic distance conditions tested here should provide information about possible effects in a real speech production setting, provided they yielded analogous coil distortion values.

The average data were subtracted from the values obtained with the artificial palate subject to no electrode activation (i.e., with 0 ''on'' electrodes). The reason for choosing a nonactivated palate instead of no palate as reference condition was the difficulty of pulling out the artificial palate from the magazine without affecting the position of the coils when the former was parallel to the latter.

The data were obtained in a similar fashion to the perpendicular case: Each relevant measurement was preceded and followed by a reference measurement taken with the artificial palate subject to no contact activation (i.e., with 0 ''on'' electrodes). The preceding and following reference measurements were averaged and subtracted from the relevant measurement. This operation was repeated three times. The three resulting values were averaged among themselves following the procedure for the perpendicular condition.

In order to find out whether the transducer coils would interfere with the linguopalatal contact pattern, the second author of this paper read a list of sequences with an artificial palate in place both with and without three coils attached to the midline of the tip, blade, and dorsum. The fast setting glass ionomer cement ESPE Ketac Bond was used for attaching the coils to the tongue surface (the cement extended about 1 mm around the coils). The tongue tip coil was placed

TABLE I. Effects on coil position from differences in contact size on an artificial palate placed perpendicularly to the magazine. They are reported as a function of coil position number (1–9; see Fig. 1) and contact size (0, 22, 40, and 62 electrode activation; see Fig. 2, top and middle); effects for the mold condition alone are also given. Values (in mm) represent differences in coil position between the mold and contact size conditions, on the one hand, and a condition involving no artificial palate or mold, on the other hand. They were averaged across sweeps and artificial palates for the *x* and *y* components (within parentheses) and for the Euclidean distance r (below).

	Mold	0 electrodes	22 electrodes	40 electrodes	62 electrodes
1	(0,0.01)	(0,0)	(−0.04,0.04)	(−0.07,0.06)	(−0.03,0.08)
	0.01	0	0.06	0.09	0.08
2	(−0.01,0)	(−0.02,0.02)	(−0.04,0.07)	(−0.04,0.05)	(−0.04,0.08)
	0.01	0.03	0.08	0.06	0.09
3	(−0.02,0.02)	(0,0.06)	(−0.08,0.07)	(−0.11,0.07)	(−0.12,0.13)
	0.03	0.06	0.11	0.13	0.18
4	(0,0)	(−0.06,−0.04)	(−0.08,0.09)	(−0.13,0.13)	(−0.15,0.15)
	0	0.07	0.12	0.18	0.21
5	(−0.05,0.02)	(−0.05,0.03)	(−0.10,0.09)	(−0.17,0.10)	(−0.16,0.11)
	0.05	0.06	0.13	0.20	0.19
6	(−0.04,−0.01)	(−0.03,0.05)	(−0.09,0.08)	(−0.08,0.09)	(−0.10,0.12)
	0.04	0.06	0.12	0.12	0.16
7	(−0.05,0.05)	(−0.01,0.06)	(−0.07,0.08)	(−0.10,0.08)	(−0.12,0.10)
	0.07	0.06	0.11	0.13	0.16
8	(−0.03,0.04)	(−0.03,0.07)	(−0.05,0.10)	(−0.05,0.08)	(−0.07,0.10)
	0.05	0.08	0.11	0.09	0.12
9	(0.04,−0.01)	(0,0.07)	(−0.03,0.06)	(−0.04,0.09)	(−0.02,0.09)
	0.04	0.07	0.07	0.10	0.09

TABLE II. Effects on coil position from differences in contact configuration on an artificial palate placed perpendicularly to the magazine. The number of activated electrodes is always about 30 (see Fig. 2, bottom) and coil position varies (1–9; see Fig. 1). Values (in mm) represent differences in coil position between two contact configuration conditions, on the one hand, and a condition involving no artificial palate or mold, on the other hand. They were averaged across sweeps and artificial palates for the x and y components (within parentheses) and for the Euclidean distance r (below).

	30 lateral electrodes	32 central electrodes
1	(−0.04,0.06) 0.07	(−0.03,0.06) 0.07
2	(−0.08,0.15) 0.17	(−0.06,0.10) 0.12
3	(−0.10,0.09) 0.13	(−0.10,0.12) 0.16
4	(−0.13,0.09) 0.16	(−0.15,0.07) 0.16
5	(−0.13,0.07) 0.15	(−0.13,0.08) 0.15
6	(−0.07,0.13) 0.15	(−0.08,0.11) 0.14
7	(−0.09,0.10) 0.13	(−0.08,0.13) 0.15
8	(−0.04,0.09) 0.10	(−0.03,0.09) 0.09
9	(−0.02,0.03) 0.04	(−0.03,0.04) 0.05

at the front alveolar zone (approximately in front of the frontmost row of electrodes on the artificial palate). The tongue blade coil was placed about 1.6 cm behind the tongue tip coil at the back alveolar and front palatal zone (approximately in front of the fifth row of electrodes). The dorsum coil was positioned about 1.6 cm behind the tongue blade coil somewhere at the mediopalatal zone (approximately in front of the seventh row of electrodes). Reference coils were also placed on the bridge of the nose and on the upper incisors. Linguopalatal contact was recorded for five repetitions of the sequences /ti'Cit/, /ta'Cat/, and /tu'Cut/ with the intervocalic consonants alveolar /l/ and /n/, postalveolar /ʃ/, alveolopalatals /ʎ/ and /ɲ/, and velar /k/. (Lingual movement data were also recorded but will not be presented here.) Linguopalatal contact patterns for each sequence were averaged across repetitions and analyzed at the most representative temporal frame for each consonant, i.e., alveolar closure midpoint for /l/ and /n/, alveolopalatal closure midpoint for /ʎ/ and /ɲ/, closure midpoint at the backmost palatal row for /k/, and alveolopalatal constriction maximum for /ʃ/.

II. RESULTS

A. Effects on coil position

Table I shows effects for the perpendicular palate condition as a function of coil position number and contact size averaged across sweeps and artificial palates. Effects on the table are given for the horizontal component (x), for the vertical component (y), and for the Euclidean distance (r). They correspond to location differences in mm between coil measurement values for each of the contact activation conditions (including the 0 electrode and mold conditions) and those obtained without the presence of artificial palate or mold in the magnetic field. As expected, effects never reached 0.1 mm when measurements were taken with the mold alone or with an artificial palate with 0 ''on'' electrodes. Experimental sensitivity for each coil in the EMA equipment (conveniently calibrated) was found to be 0.12 mm for the x and y components, and 0.17 mm for r. The contact activation conditions involving 22, 40, and 62 ''on'' electrodes yielded small effects. Only for the experimental condition prone to yield maximal palate-to-coil interference, i.e., a good deal of contact activation and a short distance between the coil and the artificial palate, did the effects exceed the noise level slightly. The maximum effect was 0.15 mm for the x and y components and 0.21 for r; effects averaged 0.1 mm for the x and y components and 0.13 mm for r. These effects are comparable across artificial palates since standard deviations (not given in Table I) are below the experimental sensitivity level; moreover, variations throughout each 5-s file were also smaller than this level. The effects increase slightly with the degree of contact activation, and tend to decrease progressively as coil-to-artificial palate distance increases from coil 5 to coils numbered 1 and 9 in the table.

According to Table II (which is analagous to Table I), changes in linguopalatal contact configuration (i.e., lateral versus central) when the number of ''on'' electrodes stays about the same do not affect coil position. Effects for r barely exceed 0.15 mm and decrease as we approach coils numbered 1 and 9.

The effects for the parallel palate condition in Table III correspond to differences in mm between coil measurements for each of the contact activation conditions and those obtained with an artificial palate with 0 ''on'' electrodes in the magnetic field. For both measurement conditions, the effects are always below the noise level for the EMA system and

TABLE III. Effects on coil position exerted by a fully activated artificial palate (62 ''on'' electrodes) placed parallel to the magazine. They were measured for different coil positions (1–5; see Fig. 1) and two palate-to-magazine distances (6–7 mm, 4–5 cm). Values (in mm) represent differences in coil position between full palate activation and no palate activation at each of two parallel distances from the magazine. They were averaged across sweeps and artificial palates for the x and y components (within parentheses) and for the Euclidean distance r (below).

	1	2	3	4	5
6–7 mm	(0,0) 0	(−0.01,0.03) 0.03	(0,0) 0	(0,0) 0	(0,0.02) 0.02
4–5 cm	(0,−0.01) 0.01	(0,0) 0	(−0.01,0.02) 0.02	(0.01,−0.01) 0.01	(−0.01,0.03) 0.03

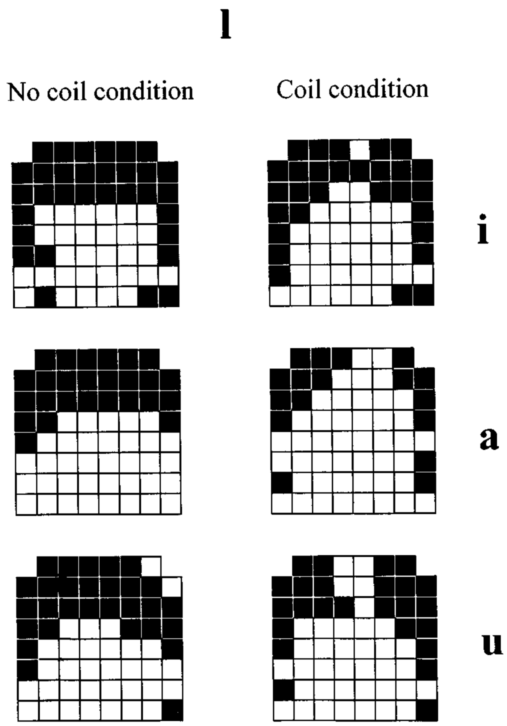

FIG. 3. Linguopalatal contact patterns for /l/ with adjacent /i/, /a/, and /u/ obtained under the coil and no coil conditions.

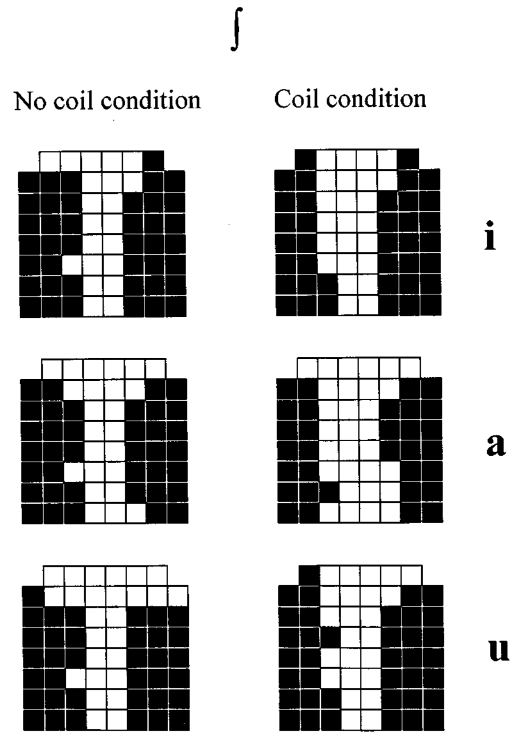

FIG. 4. Linguopalatal contact patterns for /ʃ/ with adjacent /i/, /a/, and /u/ obtained under the coil and no coil conditions.

thus even smaller than those for the perpendicular palate condition. Therefore, no differences were obtained between coil measurements when the artificial palate was parallel to the magazine with all activated electrodes and with no electrode activation. As for the perpendicular condition, signal variations over time within each file in the parallel condition were also below the noise level.

B. Effects on linguopalatal contact activation

Figures 3–5 show linguopalatal contact configurations for the coil (right) and the no coil (left) conditions.

For alveolar /l/, the coil condition causes a central channel to occur at the alveolar zone which can be mostly attributed to the tongue tip coil interfering with frontmost contact. There are essentially no contact differences between the two conditions at the palatal zone.

Postalveolar /ʃ/ exhibits a larger central channel in the coil versus no coil condition due to one more column of electrodes on the left side of the palate remaining free of contact when coils are attached to the tongue surface. Loss of contact is mostly found along the alveoloprepalatal zone and should be attributed to the tongue blade coil.

Alveolopalatal /ɲ/ shows a large contact surface. The presence of a central channel in the coil versus no coil condition should be mostly attributed to the tongue blade coil blocking electrode activation near the midline. The tongue tip and the tongue dorsum coils may presumably prevent contact from occurring at the front palate (in the /i/ and /a/ contexts) and at the back palate (in the /i/ context), respectively.

III. SUMMARY AND CONCLUSIONS

Rather small effects on coil position were obtained with the palate placed perpendicularly; they increase slightly with a decrease in coil-to-palate distance and with an increase in EPG contact activation. Distortion values were much smaller

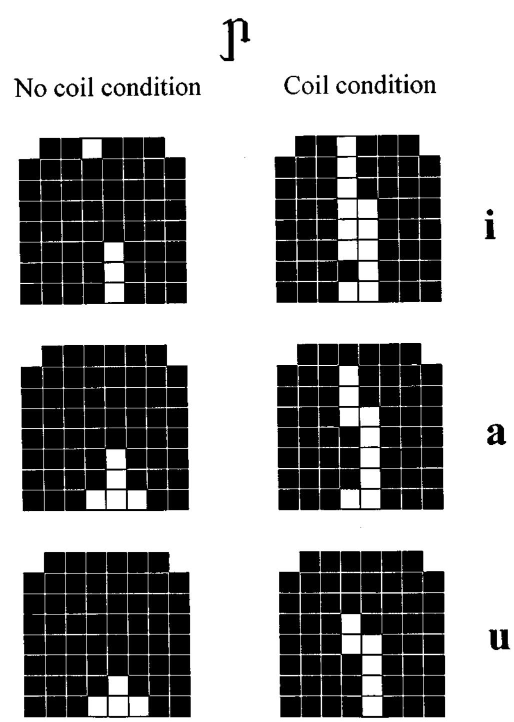

FIG. 5. Linguopalatal contact patterns for /ɲ/ with adjacent /i/, /a/, and /u/ obtained under the coil and no coil conditions.

when the palate was placed horizontally. These effects are probably due to local changes in the magnetic field caused by electrode activation.

Coil placement interfered with palatal contact locally (i.e., near its midline), at the alveolar zone for alveolar /l/, and at the alveolar and palatal zones for alveolopalatal /ɲ/. Some loss of central contact occurred for /ʃ/. Failure for the EPG hardware to register contact could be due to the following factors: (a) the Ketac cement being an electrical isolator; and (b) the housing of the EMA transducer coils having a much higher electrical resistance than the lingual mucosa and the threshold setting of the EPG unit not being sensitive enough to detect contact at coils location. Modifications in the state condition of one or both of these factors might diminish the degree of coil-to-palate interference.

While the negligeable effects on coil position support the simultaneous use of EMA and EPG, differences in central contact using the two techniques do not. In our view this problem can be accounted for more easily than if distortions affected coil position. It is suggested that EPG data recorded without tongue coils on the tongue surface be matched with EPG data obtained with coils attached to the tongue. Inspection of the two linguopalatal contact patterns for the same sequences should provide precise information about the areas of the palate where overlap between coils and palate occurs; data reported in this paper reveal that those areas of overlap are consistently found along one or two central columns. Therefore, it is highly advisable to measure the position of the tongue coils with respect to the electrodes of the artificial palate in the experimental session. Once this position is known, it should be possible to recover the original contact patterns with the aid of contact data for the same sequences obtained without tongue coils.

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