

Influence of a standard electropalatography artificial palate upon articulation: A preliminary study

Running Title: Influence of an EPG palate on articulation

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## **Abstract**

This study investigated the influence of a standard EPG palate upon speech articulation in three normal speakers under standard EPG testing conditions. Three adult females aged 26, 31, and 34 read the experimental phrase “Say CV again” five times under three experimental conditions: normal speech (without a palate in-situ), 45 minutes after EPG palate insertion, and three hours after EPG palate insertion. Consonants and vowels commonly used in EPG research were studied and included /t/, /s/, and /j/ in the /i/, /a/, and /u/ vowel environments. Perceptual and acoustic analysis of the data was completed.

Results revealed varied patterns of adaptation across the three participants. Perceptual analysis suggested that two of the participants adapted to the presence of the palate; however, one did not. The presence of the palate resulted in significant changes to consonant duration for all three participants. Spectrally, production of /t/ was unaffected by the presence of the palate, while articulation of fricatives varied across the participants. Paired with a previous study examining the effects of an EPG palate upon speech articulation [1], the present data suggest that researchers and clinicians alike should be aware of the potential perturbing effects of the palate.

## Introduction

Electropalatography (EPG) is now a relatively common approach in the assessment and treatment of speech articulation disorders, particularly in the United Kingdom and Australia. This technique has provided valuable insight into the tongue-palate speech articulation characteristics of both children [2, 3] and adults [4-11] and has consistently resulted in positive treatment outcomes for children with articulation disorders [12-14]. Use of EPG requires that participants wear an individually moulded, acrylic artificial palate that resembles an orthodontic retainer. The artificial palate is approximately one to two millimetres thick and fits snugly against the contours of the hard palate, attaching via wires to the teeth.

When the artificial palate is initially inserted, most participants exhibit distorted speech articulation and/or increased salivation. It is generally accepted by EPG researchers that individuals require between 45 minutes and three hours of desensitisation to adapt to the presence of the palate within the mouth [8, 15, 16]. However, EPG studies do not report detailed comparisons of speech articulation prior to, and following, artificial palate insertion. Generally, participants are considered to have *adapted* when (1) speech articulation is observed by the examining researcher to have returned to a similar level of articulatory precision as without the palate in-situ and (2) excess salivation has ceased.

The lack of research data formally examining the perceptual and acoustic effects of the EPG palate upon speech articulation has attracted criticism. Weismer and Bunton [17] stated that “the demonstrated influence of pseudopalates on articulatory behaviour makes it difficult to evaluate the generalizability of findings from electropalatographic studies of speech production” (p. 2882). This seems a particularly pertinent issue as, in recent times, EPG has been used to make inferences about underlying speech motor control processes in healthy and neurologically impaired speakers [18]. Given the potential influence of the palate upon articulation, careful

analysis of the effects of the appliance, both perceptually and acoustically, are required to ensure that valid interpretations can be drawn from the findings of EPG research studies.

A recent investigation has provided initial data to address the lack of research in this area. McLeod and Searl [1] examined adaptation to an EPG palate in seven adult speakers of Australian English over a five-hour period on day one (inclusive of two hours with the palate removed) and a three-to-four hour period on day two. Spectral and durational analyses were conducted on the consonants /s/ and /t/ during production of the phrases /ə ti/ and /ə si/. Spectral analysis revealed that initially, the palate negatively effected consonant articulation; however, articulation normalised following 60 minutes and two hours adaptation for /t/ and /s/ respectively. There was no significant change to measures of consonant duration across time periods for either consonant. Perceptually, one expert rater (not blinded to the study purpose) completed two ratings upon listening to a counting (1-20) and short reading task. The rater was asked to provide a yes/no judgement in response to the question “is this person wearing an EPG palate” and to rate speech naturalness and distortion on an 11-point equal interval scale. Findings indicated that impairment to speech naturalness and distortion was minimal; however, the expert rater was able to determine accurately that the participant was or wasn’t wearing a palate in 76% of cases for the counting task and 81% of cases for the reading of the rainbow passage.

The study by McLeod and Searl [1] has provided a valuable first step towards improved understanding of the effect of standard EPG palates upon speech production. However, much remains to be examined. For example, how do naive listeners perceive speech articulation with an EPG palate in-situ? Such data is required for research to conclude that influences upon speech naturalness are minimal. Furthermore, a wider variety of consonants, including variation in place and manner of articulation, should be investigated to provide further confirmation of the minimal perturbing effects of the EPG appliance. Therefore, this study aims to extend the work of

McLeod and Searl [1] and undertake detailed perceptual and spectral analysis of three individuals articulation of /t/, /s/, and /j/ across the conditions of normal speech (without the palate in-situ) and the commonly used adaptation times of 45 minutes and three hours.

## **Method**

### ***Participants***

Three females aged 31, 26, and 34 years participated in the study. They are henceforth referred to as participant one (P1), participant two (P2), and participant three (P3) respectively. All exhibited normal dental occlusion and reported normal hearing and no history of neuromotor or speech disturbance. They were selected through previous participation in EPG studies conducted by the Motor Speech Research Centre, University of Queensland [4-6]. There were no special criteria for selection, only that individuals had not participated in an EPG investigation for a period of two or more years and were available for re-assessment using EPG. A period of two years was chosen to minimise the effects of any previous periods of adaptation to the appliance.

### ***Data Collection***

Nine CV words embedded within the carrier phrase “say CV again” were repeated five times under three speaking conditions by each participant. Consonants and vowels commonly used in EPG research were studied and included /t/, /s/, and /j/ in the /i/, /a/, and /u/ vowel environments. This resulted in 45 phrases per speaker for each speaking condition. The experimental stimuli were presented in random order across the three conditions.

The 45 experimental phrases were read and recorded at three speaking conditions: (1) normal speech (without the artificial palate in-situ), (2) 45 minutes following the insertion of the

palate, and (3) three hours following insertion of the artificial palate. Participants were required to wear the artificial palate for the entire duration of data collection (approximately three hours) and during this time were instructed to converse as much as possible while going about their daily work activities. Speech was recorded using a head mounted microphone (Sony ECM-3 electret condenser microphone) positioned approximately 5cm from the mouth. The microphone signal was captured at a sampling rate of 44 kHz with a Sony Digital Audio Tape (DAT) recorder. All testing was conducted in a sound treated room under standard test conditions.

A custom made artificial palate was worn by each of the participants. This palate was the standard EPG artificial palate employed in all investigations that use the Windows EPG system (WinEPG). Each palate was approximately one to two millimetres thick and was moulded to fit the contours of the hard palate. Two sets of wire clasps held the palate in place on the roof of the mouth. The posterior wire clasps fitted over the molars and the anterior clasps were placed between the lateral incisors. Two sets of wires that ran along the outside of the teeth and out the corners of the mouth connected the artificial palate to a data interface and computer terminal.

### ***Perceptual Analysis***

A compact disc (CD) was generated containing randomised presentation of the participant's productions of the experimental phrase. The CD consisted of a total of 405 stimuli with a six-second period of silence between each production (nine phrases x five repetitions x three speaker conditions x three speakers). The recorded phrases were presented to five naïve listeners; all females aged between 20 and 25 who were undergraduate students of speech-language therapy at the University of Canterbury, Christchurch, New Zealand. All naïve listeners reported normal hearing.

Listeners were asked to complete a rating of the speech stimuli using a similar procedure to that of Weismer and Bunton [17]. Raters were instructed “You will hear a series of repetitions of the phrase, *say \_\_\_ again*; please listen carefully and decide if you think the speaker is wearing an artificial palate or not, then place a tick in the appropriate column (yes/no) beside the phrase number”. Only those phrases with 80% inter-judge agreement (i.e. in which four out of five of the listeners responded similarly) were included in the analysis of results [17]. These were termed “consistently” judged and amounted to 253 of the total 405 productions (63% of the total number of phrase recordings).

### *Acoustic Analysis*

The CV portion of each phrase recording was subjected to acoustic analysis using a commercially available computer system (Kay CSL 4300B). These audio signals were digitised at a rate of 20 kHz, using 16 bits of quantisation. Measures employed previously in articulatory perturbation studies were used to determine the effect of the artificial palate upon speech production [17, 19]. The measures included were as follows:

(i) *Durational measures*: An amplitude-by-time display of the CV waveforms was employed in the analysis of all durational measures. For /t/, voice onset time (VOT) was measured from the beginning of the burst to the onset of periodicity associated with the subsequent vowel. For /s/ and /ʃ/, duration was measured from the onset of frication noise to the beginning of periodicity for the subsequent vowel [19].

(ii) *Consonant spectra*: For /t/, /s/, and /ʃ/ spectral analysis of the centroid frequency (M1) and kurtosis of the distribution (M4) was conducted [20]. These moments reflect the concentration and peakedness respectively of the spectral energy distribution during consonant production [20].

For determination of /t/ spectra, a 20ms section of the consonant was selected beginning at the onset of the burst. Spectral analysis of /s/ and /ʃ/ was completed using a 50ms window as positioned at the midpoint of the consonant amplitude-by-time waveform. Spectral characteristics of each consonant were determined on the basis of long-term spectral analysis (LTA). The LTA display of each consonant was created through an averaging of individual Fast Fourier Transform (FFT) computations performed every 23 msec across the entire duration of the consonant [21]. A full Hamming window was used.

### ***Reliability***

Re-analysis of 20% (81 repetitions) of the acoustic data set was conducted for reliability purposes. To determine intra-judge reliability, the investigator who performed the initial measurements also performed the second set of reliability measures. To determine inter-judge reliability, an investigator not involved in performing the original measures performed the second set of reliability measures. Pearson's product moment correlations were conducted to test the reliability between the first and second set of measures. For intra-judge reliability, correlation between the first and second set of measures for consonant duration was 0.998, with an average absolute between-measure difference of 1.95ms. For M1 and M4, the correlation was 0.965 and 0.97 with average absolute differences of 189 Hz and -0.043. Correlation between the first and second judges for consonant duration was 0.996, with an average absolute difference of 5.62ms. For M1 and M4, the inter-judge correlations were 0.972 and 0.95, with average absolute differences of 305 Hz and 0.64 respectively.



### *Statistical Analysis*

Statistical analysis was completed using Friedman Repeated Measures Analysis of Variance on Ranks at  $\chi^2 < 0.001$  (Bonferroni-adjusted for comparisons). Normality and homogeneity of variance could not be assumed; therefore, the non-parametric statistical test was chosen. Post-hoc analysis was completed using alpha-adjusted Tukey pairwise multiple comparison procedures at  $p < 0.05$ .

## **Results**

### *Perceptual Analysis*

Figure 1 shows the percentage of phrase repetitions, by consonant, correctly judged to have been spoken without the palate in-situ during the no palate condition. As expected, naïve listeners correctly identified that the speakers were not wearing an artificial palate during the no palate condition. Only production of the consonant /s/ for P1 and P3 demonstrated any reduction from 100% correct judgment, though the percentage correct identification did not drop below 89%. Figures 2 and 3 contain the percentage of repetitions judged correctly and incorrectly at the 45 minute and three hour conditions. The results show that for P1 the naïve listeners correctly identified that the participant *was wearing* an artificial palate at both the 45 minute and three hour conditions. These results indicated that P1 did not adapt to the presence of the artificial palate. In contrast, the results showed that P2 and P3 exhibited high levels of percentage incorrect judgement by the three hour stage. That is, the naïve listeners incorrectly indicated that the participants were not wearing a palate when they were. These results indicate that P2 and P3 likely adapted, perceptually, to the presence of the palate.

*(Insert figures 1-3 near here)*

## ***Temporal Analysis***

### ***Consonant Duration***

Table 1 contains individual mean and grouped results for measures of consonant duration. Overall, P1 and P3 exhibited reduced durations at both the 45-minute and three-hour conditions. In contrast, P2 demonstrated no changes across the conditions. Statistical analyses of results confirmed these observations, with both P1 and P3 demonstrating a significant reduction in overall consonant duration following three hours of adaptation ( $p < 0.05$ ).

Analysis according to phoneme type indicated that P1 articulated the three consonants with a significantly reduced duration at 45-minutes post-insertion ( $p < 0.05$ ) with fricatives maintaining the reduced duration at three hours post-insertion. P3 articulated /t/ with a reduced duration at both the 45-minute and three-hour conditions; however, P3's fricative durations remained unchanged across the three conditions ( $p > 0.05$ ). The results for P2 revealed variable patterns of segment durations according to phoneme type. Significant reductions ( $p < 0.05$ ) in the duration of both /t/ and /s/ were observed at the three-hour condition. In contrast, the results for /ʃ/ demonstrated a trend towards increased duration following both 45 minutes and three hours of adaptation.

*(Insert Table 1 near here)*

## ***Spectral Analysis***

### ***Centroid frequency (M1)***

Table 2 contains individual and grouped consonant results for M1. Statistical analysis of the collapsed consonant data indicated that P1 demonstrated a significant reduction ( $p < 0.05$ ) in M1 between the no palate and 45-minute condition and that this reduction was maintained at the

three-hour condition ( $p < 0.05$ ). Analysis of P1's individual consonant results revealed a significant reduction in M1 for fricatives ( $p < 0.05$ ) at both the 45-minute and three-hour conditions. P1's production of /t/ was unaffected with similar ( $p > 0.01$ ) M1s observed across the sampling periods.

While, overall, P2 exhibited similar M1 values across conditions, fricative production was affected. Analysis revealed a significant reduction in M1 for /s/ at both the 45-minute and three-hour conditions. However, a significant increase in M1 was observed for /ʃ/ at the three-hour period. For P3, M1 values appeared to reflect a process of adaptation with a significant difference overall between the no palate and 45-minute conditions ( $p < 0.05$ ); however, no significant differences in M1 ( $p > 0.05$ ) between the no palate and three-hour conditions. This pattern was statistically significant for /ʃ/ with a trend towards similar results observed for /s/. P3's data for /t/ were similar across the sampling periods ( $p < 0.01$ ).

*(Insert Table 2 near here)*

#### ***Kurtosis (M4)***

Table 3 contains individual participant's mean and standard deviation values for kurtosis (M4) for both individual consonants and collapsed across consonants. Overall, a similar pattern emerged for P1 and P2, both of whom demonstrated a significant reduction ( $p < 0.05$ ) in M4 at the 45-minute and three-hour conditions. Similarly, when individual consonants were examined, both P1 and P2 exhibited significant reductions ( $p < 0.05$ ) in M4 for /s/ when the no palate condition was compared with both the 45-minute and three-hour condition indicating a reduction in the "peakedness" of the spectral distribution. In contrast, overall results for P3 revealed similar M4

values across the conditions. When individual consonants were examined, P3 exhibited a significant increase in M4 for /t/ ( $p < 0.05$ ) at both the 45-minute and three-hour conditions.

*(Insert Table 3 near here)*

## **Discussion**

### ***Perceptual Analysis***

The perceptual component of the study required listeners to perceive the presence or absence of an EPG palate in speech samples. Presumably, if speakers successfully adapted to the EPG palate, listeners would be unable to perceive the presence of the palate. Results from the participants showed a clear delineation between P1 and both P2 and P3. In the case of P1, results demonstrated that adaptation did not occur (perceptually) across /t/, /s/, and /ʃ/ as the listeners correctly identified the absence/presence of the EPG palate with greater than 80% accuracy across all sampling periods. In contrast, both P2 and P3 were found to adapt to the palate, as evidenced by low percentage correct identification scores at 45 minutes and, in particular, three hours post insertion of the palate. Overall, there was no clear pattern in regard to adaptation by consonant type for any of the participants. They were judged to have either adapted to the palate across all consonants types (P2 and P3), or not (P1).

The current finding that one of the three participants did not adapt to the presence of the palate compares favourably with the results of McLeod and Searl [1] who also reported that approximately one third (i.e., two of seven) of their participants exhibited poor adaptation (perceived as unnaturalness and articulatory distortion). Therefore, it appears that while the majority of individuals are able to adapt their speech to the presence of an EPG palate, some participants exhibit difficulty, or do not adapt, even following extended adaption time periods.

### *Temporal Analysis*

The combined results of the temporal analysis for the three consonant types revealed the following major patterns: (1) the duration of consonant articulation generally remained either unchanged or decreased across the three sampling periods, (2) the durations of /s/ and /j/ were more variable than /t/, and (3) consonant duration at 45 minutes did not commonly differ significantly from the durations at the three-hour sampling period.

Across all participants, VOT of /t/ decreased following insertion of the EPG palate. This result is consistent with previous articulatory perturbation studies that reported a reduction in both VOT [19] and stop gap duration [22] of /t/ upon insertion of thick and thin artificial palates. However, the present results do not closely align with those of McLeod and Searl [1] who reported no changes to stop gap duration preceding /t/ in their study of seven speakers of Australian English. Although the measures are not identical, it was surprising to find dissimilar results. The long VOT values reported in the current investigation, ranging from 82 msec to 139 msec across participants, most likely reflect the common finding of long VOTs among female speakers [23, 24]. Interestingly, the present study was confined to female speakers, while McLeod and Searl [1] considered three female and four male speakers. It is possible that gender differences across the two studies contributed to the differing results. Regarding the current study findings of reduced VOT with palate insertion, two explanations are offered. Firstly, it is possible that adaptation to the palate may have been accompanied by increases in speaking rate, which would have resulted in a decrease in /t/ VOT at the 45-minutes and 3-hour conditions. While speaking rate was not measured in the present study, this explanation appears unlikely as similar reductions in duration were not found for the remaining two consonants. Alternatively, it is

possible that reduced VOT for /t/ reflects speaker-specific temporal adjustments undertaken to maintain the perceptual integrity of /t/ articulation.

The durational data for articulation of /s/ and /ʃ/ was less consistent across participants. P1 and P3 demonstrated reduced durations across the sampling periods; however, not to the same extent as found for VOT. Conversely, P2 demonstrated a slight increase in /s/ and /ʃ/ duration across time. It is possible that the variable consonant durations for /s/ and /ʃ/ were related to the articulatory precision required for fricative production. Specifically, /s/ requires a complex lingual gesture to be maintained in the alveolar region [25], the point at which an EPG palate is often at its thickest. It is therefore possible that the individual variation observed reflects speaker-specific temporal adjustments undertaken as part of the adaptive process.

The findings of reduced /t/ duration and variable fricative durations demonstrate that the insertion of an EPG palate resulted in temporal articulatory changes for the three participants studied. While these durational changes occurred, it was obvious to the group of naïve listeners that only P1 was wearing an EPG palate at the 45-minute and three-hour conditions. Therefore, it is possible that each speaker made compensatory adjustments to consonant duration in an attempt to adapt to the presence of the EPG palate. P2 and P3 were successful in this undertaking; however, P1 was not. Further, it would seem that the temporal adjustments required to produce perceptually acceptable articulation may be participant-dependant, reflected through the variation observed across participants in the current study.

### *Spectral Analysis*

Clear patterns in the spectral composition of /t/ and /s/ were found across the three participants. However, individual variation existed for /ʃ/ articulation. An adaptation continuum

appeared to exist with /t/ least susceptible spectrally to the perturbing influence of the palate, followed by /ʃ/ and /s/ respectively. Following three hours with the palate in-situ, all participants generally articulated /t/ with similar centroid frequency and kurtosis of the spectral distribution compared to the no palate condition. The finding of a limited effect of the palate upon the spectral characteristics of /t/ was consistent with previous research [1, 19, 22]. In the light of the consistent reduction in the duration of /t/ across sampling periods, the lack of change in the acoustic spectrum would suggest that the palate has a greater influence on the temporal features of /t/ rather than its spectral features.

Similar to previous studies [1, 19, 22], the insertion of the EPG palate resulted in a reduced centroid frequency and greater spread of spectral energy across frequencies during /s/ production for both P1 and P2. These acoustic results are generally thought to be associated with a posterior shift in the place of articulation and shorter, wider fricative constrictions [26]. In contrast, P3 demonstrated little change to any spectral parameters of /s/ with the palate in-situ. This lack of change would suggest that minimal articulatory changes were required to produce /s/ accurately with the palate in-situ. Alternatively, if any strategic articulatory reorganisation was required for production of /s/, it was completed prior to the 45-minute assessment condition.

Given the pattern of spectral findings for /s/, it is important to consider why P1 and P2 exhibited changes in /s/ spectra while P3 did not. While not directly measured in the present study, it was informally observed that P3 exhibited a wider and flatter hard palate than either P1 or P2 who both exhibited smaller mouths and a high palatal arch. The differences in structural morphology of the three participants may have allowed the individual with a greater articulatory space to articulate /s/ more easily in the presence of an EPG palate. In addition, the role of oral sensation in producing speech with an EPG palate in-situ should not be overlooked. It is possible

that a continuum of susceptibility to oral perturbation exists, with some individuals exhibiting heightened sensation and therefore, poorer adaptive abilities or alternatively, reduced (while still within a normal range) oral sensation resulting in greater adaptive ability.

The spectral results for /ʃ/ varied across participants; however, P1 exhibited the greatest changes in production followed by P2, then P3. For P1, similar spectral findings for /ʃ/ were achieved to /s/ likely indicating that strident fricatives, in general, were articulated with a retracted tongue position and/or wider fricative groove with the palate in-situ. In contrast, the results for P2 were unusual, with the participant exhibiting a similar M1 for /ʃ/ at the 45-minute condition compared to the no palate condition; however, a significant increase in M1 occurred following three hours of use. Finally, data for P3 revealed a significant decrease in M1 following 45 minutes; however, similar spectral characteristics for /ʃ/ following three hours of adaptation. These results indicated that between the 45-minute and three-hour condition, some form of compensation occurred resulting in similar spectral distribution both with, and without, the palate in-situ.

### **Conclusions**

This study is one of only two to investigate the influence of a standard EPG artificial palate upon speech articulation. The findings of the study revealed that two of the three participants were perceived to have adapted to the presence of the palate. Corresponding acoustic analysis of the speech signal revealed changes to consonant articulation in the presence of the palate across all participants. In general, the majority of acoustic changes occurred at some point between the insertion of the palate and following the 45-minute sampling period.



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**Table 1:** Means of durational measures in milliseconds for each participant for both individual sounds and collapsed across consonant. Means exhibiting different corresponding letters in subscript (e.g., *a* vs *b*) were statistically significant using alpha-adjusted post-hoc analysis at  $p < 0.05$ .

		<b>No Palate</b>	<b>45 minutes</b>	<b>3 hours</b>	$\chi^2$	<i>p</i>
P1	/t/	103 (11) <i>a</i>	79 (14) <i>b</i>	86 (13) <i>a,b</i>	14.29	<0.001***
	/s/	204 (20) <i>a</i>	156 (15) <i>b</i>	167 (18) <i>b</i>	26.53	<0.001***
	/ʃ/	209 (18) <i>a</i>	163 (14) <i>b</i>	174 (15) <i>b</i>	26.53	<0.001***
	Overall	172 (52) <i>a</i>	134 (41) <i>b</i>	142 (43) <i>c</i>	66.18	<0.001***
P2	/t/	139 (9) <i>a</i>	116 (21) <i>b</i>	122 (9) <i>b</i>	12.40	0.002**
	/s/	215 (11) <i>a</i>	222 (13) <i>a,b</i>	228 (20) <i>b</i>	9.73	0.008**
	/ʃ/	215 (21)	218 (19)	228 (13)	6.53	0.038
	Overall	190 (39)	185 (53)	193 (53)	5.20	0.074
P3	/t/	100 (18) <i>a</i>	82 (11) <i>b</i>	82 (10) <i>b</i>	14.40	<0.001***
	/s/	186 (20)	197 (29)	180 (28)	4.13	0.127
	/ʃ/	191 (19)	190 (19)	183 (14)	1.86	0.395
	Overall	159 (46) <i>a</i>	156 (57) <i>a,b</i>	147 (51) <i>b</i>	11.64	0.003**

**Note:** \*\*\* =  $p < 0.001$ , \*\* =  $p < 0.01$ . Overall = mean and standard deviation values collapsed across consonant. For /t/, VOT was measured as an indicator of consonant duration.

**Table 2:** Mean centroid frequency (M1) in Hz for each participant for both individual sounds and collapsed across consonant. Means exhibiting different corresponding letters in subscript (e.g., *a, b*) were statistically significant using alpha-adjusted post-hoc analysis at  $p < 0.05$ .

		No Palate	45 minutes	3 hours	$\chi^2$	<i>p</i>
P1	/t/	2446 (1439)	2704 (1367)	2653 (827)	0.933	0.627
	/s/	8528 (481)	5236 (1433)	4961 (1283)	22.53	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
	/ʃ/	3893 (332)	2982 (858)	2944 (928)	14.53	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
Overall		4956 (2766)	3641 (1673)	3581 (1462)	22.91	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
P2	/t/	5935 (651)	5013 (909)	5350 (1002)	2.80	0.247
	/s/	7598 (1058)	5669 (1802)	6666 (1401)	12.93	0.002**
		<i>a</i>	<i>b</i>	<i>b</i>		
	/ʃ/	3373 (330)	3691 (465)	3967 (452)	12.13	0.002**
		<i>a</i>	<i>a, b</i>	<i>b</i>		
Overall		5635 (1901)	4791 (1434)	5328 (1500)	6.58	0.037
P3	/t/	3192 (1738)	2376 (1155)	2334 (1530)	5.20	0.074
	/s/	7695 (1175)	6655 (1339)	6833 (1645)	4.93	0.085
	/ʃ/	3467 (432)	2420 (905)	3463 (740)	13.86	<0.001***
		<i>a</i>	<i>b</i>	<i>a</i>		
	Overall	4785 (2409)	3817 (2318)	4227 (2370)	13.14	<0.001***
		<i>a</i>	<i>b</i>	<i>a, b</i>		

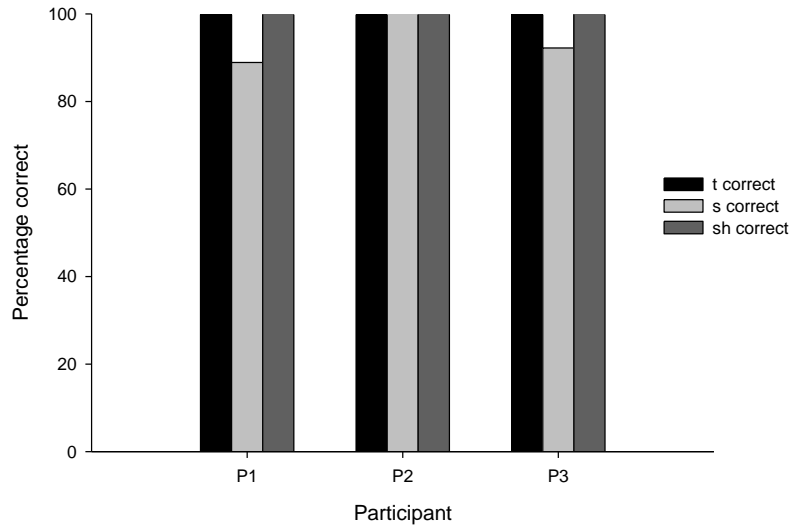
Note: \*\*\* =  $p < 0.001$ , \*\* =  $p < 0.01$ . Overall = each participants' combined means across all consonants (ie. thirty trials).

**Table 3:** Mean kurtosis of the spectral distribution (M4) for each participant for both individual sounds and collapsed across consonant. Means exhibiting different corresponding letters in subscript (e.g., *a,b*) were statistically significant using alpha-adjusted post-hoc analysis at  $p<0.05$ .

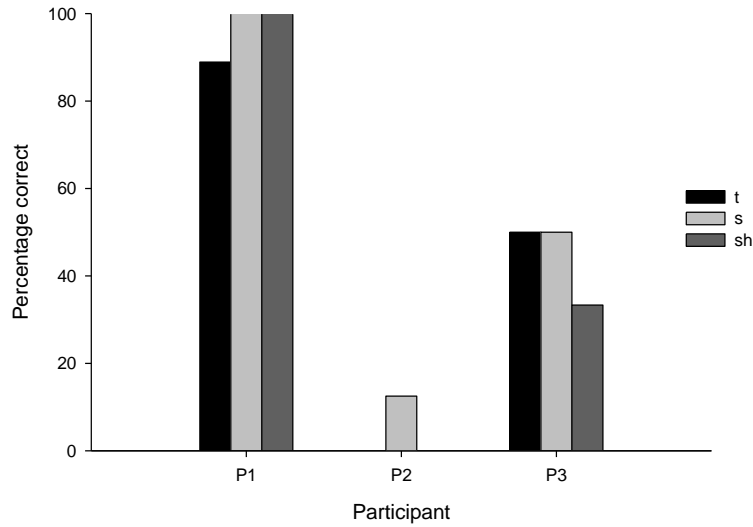
		No Palate	45 minutes	3 hours	$\chi^2$	<i>p</i>
P1	/t/	2.37 (5.10)	0.60 (3.56)	-0.46 (1.51)	3.60	0.165
	/s/	7.45 (4.56)	-1.19 (0.73)	-1.29 (0.53)	22.53	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
	/ʃ/	1.29 (1.73)	1.15 (2.51)	1.18 (3.04)	5.20	0.074
	Overall	3.70 (4.82)	0.19 (2.69)	-0.14 (2.26)	24.14	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
P2	/t/	0.69 (1.60)	-0.74 (0.95)	-0.33 (1.43)	5.73	0.057
	/s/	1.05 (1.87)	-0.82 (0.84)	-0.14 (2.06)	12.13	0.002**
		<i>a</i>	<i>b</i>	<i>b</i>		
	/ʃ/	0.76 (0.92)	0.17 (0.52)	0.17 (0.69)	3.33	0.189
	Overall	0.83 (1.49)	-0.47 (0.90)	-0.10 (1.48)	18.98	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
P3	/t/	-0.11 (2.28)	0.64 (2.07)	1.93 (4.14)	14.36	<0.001***
		<i>a</i>	<i>b</i>	<i>b</i>		
	/s/	1.31 (2.35)	0.02 (2.70)	1.33 (4.25)	3.60	0.165
	/ʃ/	0.87 (1.22)	1.03 (2.02)	0.12 (0.37)	1.86	0.395
	Overall	0.73 (2.04)	0.56 (2.27)	1.11 (6.44)	0.05	0.975

Note: \*\*\* =  $p<0.001$ , \*\* =  $p<0.01$ . Overall = each participants' combined means across all consonants (ie. thirty trials).

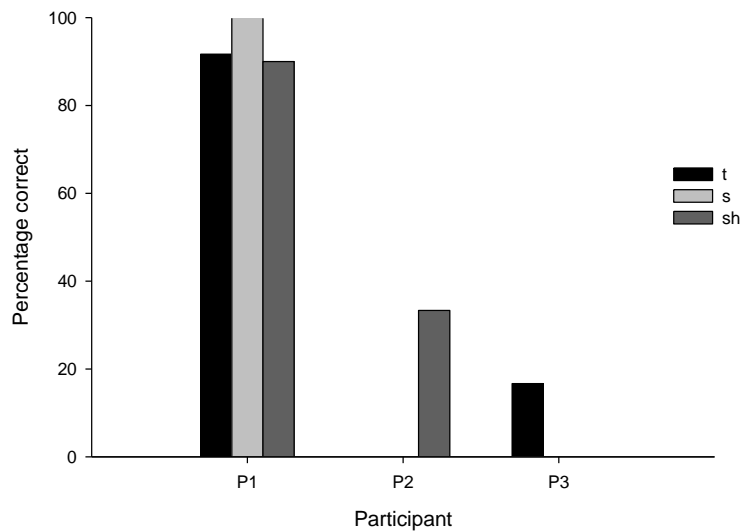
Figure 1: Percentage of repetitions judged correctly at the no palate condition. That is, the naive listeners correctly judged that participants *were not* wearing the EPG palate.



**Figure 2a:** Percentage of repetitions judged correctly at the 45 minute condition. That is, the naive listeners correctly judged that participants *were* wearing the EPG palate.

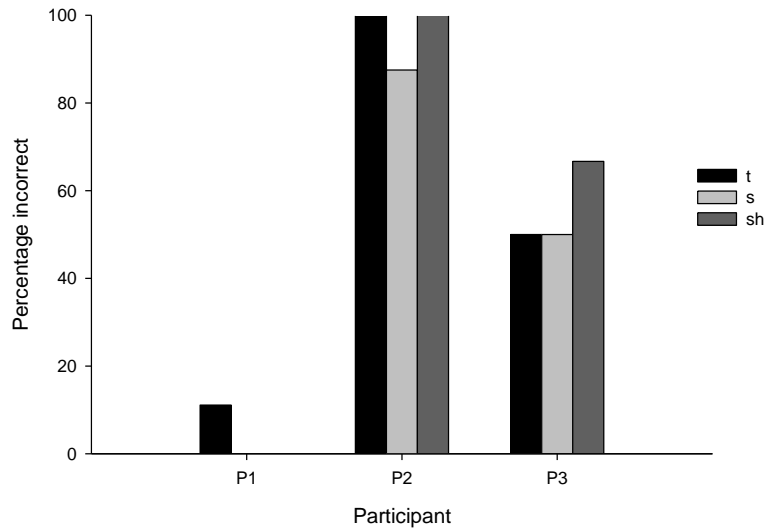


**Figure 2b:** Percentage of repetitions judged correctly at the three hour condition. That is, the naive listeners correctly judged that participants *were* wearing the EPG palate.





**Figure 3a:** Percentage of repetitions judged incorrectly at the 45 minute condition. That is, the naive listeners incorrectly judged that participants *were not* wearing the EPG palate.



**Figure 3b:** Percentage of repetitions judged incorrectly at the three hour condition. That is, the naive listeners incorrectly judged that participants *were not* wearing the EPG palate.

