Electromyographic and Intraoral Air Pressure Studies of Bilabial Stops

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INTRODUCTION

There have been a number of electromyographic (EMG) studies of the lips (Harris *et al.* 1965; Fromkin 1966; Perrin and Scharf 1970; Tatham and Morton 1968a, 1968b, 1970), at least one Lubker and Parris 1970) involving simultaneous measurement of intraoral air pressure behind bilabial stops. The experiment reported here was one of a series designed to throw light on the problem of deciding how much of the output of speech production is dependent upon the phonology and how much on the phonetics. We are not however reporting the experiment and its conclusions as supporting this or that theory, but as filling in this or that gap in our factual knowledge or clarifying this or that suspected fact. For this reason we refrain in this paper from speculation and present as much raw data as possible for readers to draw their own conclusions: we have indicated ours. Electromyographic studies lend themselves to the statistics game and we have had our fair share here.

Many EMG studies of the lips have undertaken comparisons between the occurrences of certain segments in various positions within the word, under various degrees of stress, between segments labelled in the phonology as plus/minus voice/tense, and so on. In this experiment we try to examine in a more detailed way than has usually been attempted the relationship between the contraction of just one muscle (*m. orbicularis oris*) and the event which it is principally responsible for in bilabial stop consonants — achieving lip closure. The lip closure results in (or is brought about to achieve) an increase in intraoral air pressure and so we took measurements of this variable also during the experiment.

EXPERIMENT

Two test utterances were used in the experiment: the English words ‘purr’ and ‘burr’ — i.e. [p] and [b] in initial position followed by a stressed long mid-central vowel. These items were embedded in the frame: ‘*There’s a — here*.’ Twenty-five repetitions of each item were obtained from one British English speaking subject: items 4-23 (i.e. twenty) were used for measurements, and, according to our general policy, no items were omitted for any reason.

Surface electrode EMG was used to examine contraction of *m. orbicularis oris*. An electrode was placed on the upper lip near the midline; the reference electrode was placed on the nose and the ground electrode around the wrist. The electrodes (other than the ground) were the usual silver cupped type, approximately 3-4 mm diameter, filled with electrode jelly and affixed with Blenderm tape to a slightly abraded skin surface. The signals were differentially amplified using an amplifier having a 10 megohm input impedance and a frequency response within 3 dB from 0.1 Hz to beyond the limit of the tape recorder. The signals were recorded on an Ampex SP300 tape recorder having a frequency response of 0-2.5 kHz operating in the FM mode at a tape speed of 15 ips.

Intraoral air pressure measurements were obtained using a catheter of approximately 2 mm internal diameter attached to a Frökjær-Jensen Manophone. The end of the catheter was sealed, but had a number o£ small holes punched along a 1 cm length from the seal. It was inserted high into the oral cavity *via* the mouth corner: no impedance of lip activity was observed or felt by the subject. The Manophone has a frequency response of 0-1 kHz ±3 dB, having a capacitance type pressure transducer. resultant signal was recorded on a second FM channel of the tape recorder. A reference oral microphone signal was recorded on a third channel o£ the tape recorder set to direct mode and correctly equalised (frequency response: 45 Hz-20 kHz ±3 dB).

On playback the signals were processed as follows:

- EMG signals were (a) high pass filtered at 25 Hz to remove most of any low frequency electrode movement artefacts which might be present; (b) rectified and smoothed using a low pass filter operating at 25 msec effective integration time.
- Pressure signals were low pass filtered at 50 Hz to remove most of the ripple caused by pressure variation in sympathy with vocal cord activity during voiced segments.
- Microphone signals were not processed. All filters attenuated at 18 dB/octave.

The signals were recorded simultaneously (and were therefore synchronised) on an Elema Schönander Mingograf running at 500 mm/sec. The Mingograf has a frequency response of 0-700 Hz +3 dB and a chart speed accuracy of 5%.

HYPOTHESES AND RESULTS

We begin by re-confirming the view that during tense stops a higher intraoral air pressure peak is reached than during lax stops.

Hypothesis 1

Peak intraoral air pressure is different for [p] and [b] during the stop phase: it is greater for [p].

Results

(the Appendix gives a full statement of the measurements obtained)

	mean	*s*
p	67.8	4.2
b	53.7	4.4

Peak intraoral air pressure (mm. water)

We have confirmed therefore that there is a reliable difference in mean stop peak intraoral air pressure between [p] and [b], where the ratio in this case is b : p = 1 : 1.26.

Since we have established that at least for this speaker over a number of repetitions of ‘purr’ and ‘burr’ there is a difference in the intraoral air pressure peaks during the stop phase of the plosives, we could suppose that the system is minimally balanced such that the lips are held together with little more than the force required to support the oral air pressure. Previous experiments (Tatham and Morton 1968b), where we found little difference between the peak amplitude of the EMG signals from *m. orbicularis oris* associated with [p] and [b], would indicate that this supposition is incorrect and we might be forced to guess that rather mare force is available in both [p] and [b] than is required to support the higher pressure of [p]. We should however note that Perrin and Scharf (1970) obtained results indicating that there was greater EMG peak amplitude for [p] than [b]. This disagreement suggests, not so much yet another repetition of the experiment, but a re-examination of the measurements and the statistics.

As an initial step, therefore, we check whether in this experiment [p] and [b] have different mean peak values for the EMG.

Hypothesis 2

There is no difference in mean peak amplitude of EMG from *m. orbicularis oris* between [p] and [b] in word initial position — phonological context being identical.

Results:

	mean	*s*
p	56.73	6.88
b	52.48	7.32

t = 1.84

U = 156

Mean peak amplitude of EMG from *orbicularis oris* associated with lip closure (arbitrary linear units)

- For H0 to be held at the 0.05 level for a one-tailed test *t* should have a value lower than 1 73; for a two-tailed test it should be lower than 2 09. The value of *t* obtained indicates that the peak EMG amplitude associated with [p] tends on average to be different from that of [b] with a just (but only just) acceptable level of confidence. For a difference to be established between the means the value of *U* must be smaller than 138 at alpha = 0.05 for a one-tailed test or smaller than 127 at alpha = 0.05 for a two-tailed test.

We have made the decision that for a sample as small as ours (20) the Mann-Whitney *U*-test is reliable, but that the *t*-test is not. Since the *U*-test indicates no difference between the means and the *t*-test only marginally does so, we conclude that the difference given in the table of results between the peak amplitude of EMG from *orbicularis oris* associated with [p] and [b] is statistically insignificant at the 5% level of confidence.

It might be supposed that, if there is no significant difference in mean peak amplitudes of EMG between [p] and b], it is pointless to attempt to find a correlation between peak intraoral pressure and peak EMG amplitude — this is not the case: it may well be (since both air pressure and EMG have such wide variations in their peak values) that they nonetheless correlate. At least attempting to establish correlation and finding none will underline our suspicions.

Hypothesis 3

There is a positive correlation between the peak intraoral air pressure ad peak EMG amplitude from *m. orbicularis oris* sustaining a contraction sufficient to overcome the intraoral air pressure.

Results

Neither the normal parametric correlation coefficient *(r)* nor the non-parametric Spearman rank correlation coefficient *(rS)* (reliable with the size of sample used here) indicated any significant correlation between peak intraoral air pressure and peak *EMG* amplitude from the muscle. Hypothesis 3 is therefore not supported by the available data.

Since it is obvious that contraction of *m. orbicularis oris* is principal in supporting the intraoral air pressure build-up during the stop phase of [p] and [b], we offer the explanation of finding 3. that in some sense far more contraction of the muscle is achieved than just the minimum required to support the air pressure. If this is the case then since the balance is not critical (once enough contraction is applied anything further is irrelevant one would expect a degree of variation in the contraction across several repeated tokens, and of course, as has been shown by all researchers looking at lip contraction, this is the case. We might assert then that this closure gesture is rather gross in that more (and highly varying) contraction is achieved than necessary.

However, the conclusion so far reached has been based only on measurements of peak intraoral pressure and peak EMG amplitude (*cf.* also Lubker and Parris 1970): these almost never coincide in time. Examining the event more closely it seems that there are two points in time where amount of lip contraction might be rather more critical than at the (variable) point in time where the peak occurs. These are (a) the moment of lip closure and (b) the moment of release of the built-up pressure — these points being the boundaries of the actual closure. At (a) of course the oral pressure will be at or near zero; at (b) it will for [p] be at its peak and for [b] falling very slightly from its peak (see Fig. 1).* [**footnote*: We have assumed that peak air pressure measurements occur at (b) — in any case the actual measurements were never more than 2 down at this point even for [b].]

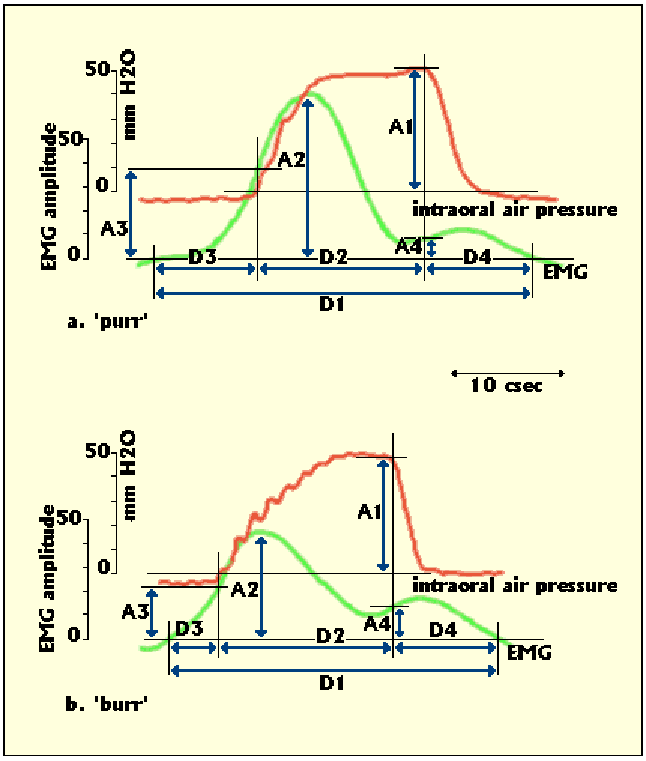

Fig. 1 Intraoral air pressure and rectified / integrated EMG from m. orbicuaris oris of typical examples of a. ‘purr’ and b. ‘burr’.

A1 — Intraoral air pressure at moment of release: mm H_2O

A2 — Peak amplitude of EMG: linear arbitrary units

A3 — amplitude of EMG at moment of closure: arbitrary units

A4 — Amplitude of EMG at moment of release: arbitrary units

D1 — Duration of EMG: csec

D2 — Duration of closure: csec

D3 — Duration of EMG before closure: csec

D4 — Duration of EMG after release: csec

We think that these two points in time are critical because they boundary a crucial phase of the stop consonant. We had informally noted from both our on work and the numerous papers in acoustic phonetics that certain parameters achieve a remarkable degree of stability (by this we mean lack of variation over repeated tokens where the subject is not varying the rate of utterance). Just such a parameter is the duration of closure for a stop consonant. Before proceeding with the assumption that the boundaries of closure are critical for contraction let us first confirm the observation about stability in closure duration.

Hypothesis 4

There is a relative stability (or lack of variation) in the duration of the closure of the lips during [p] and [b].

Results

	mean	*s*	*v*
p	12.38	0.76	6.14
b	12.23	0.7	5.72

Duration of closure (from air pressure trace)

The low values of the Pearson coefficient of variation *v* obtained confirm the hypothesis: variation in the measurements for the period of closure was small.

Having now established that closure duration is relatively stable across our sample we may assume that this fact indicates that this phase is somehow critical. If the principal muscle involved in the closure gesture is *m. orbicularis oris* we might assume that its operation is also critical. We therefore examine firstly the state of contraction at the moment of closure and secondly the state of contraction at the moment of release.

Hypothesis 5

At the moment of closure the amplitude of EMG associated with *m. orbicularis oris* contraction for lip closure for [p] and [b] is stable.

Results

Amplitude of EMG from *orbicularis oris* at moment of closure (arbitrary linear units)*.

- The phrase 'at the moment of closure' may be misleading. A reading of *EMG* amplitude was taken at the point on the trace where the air pressure began to rise rapidly indicating that closure had taken place. Notice, though, that the air pressure signal was low pass filtered at 50H which is equivalent to a 10 msec integration, whereas the EMG was integrated at 25 msec. The result of this is that the time resolution of he EMG trace is worse than that of the air pressure trace. However, selection of the point in time was arrived at from the more accurate of the two.

	mean	*s*	*v*
p	28.7	6.36	22.16
b	26.9	4.15	15 .43

The values of *v* obtained are comparable with those typically obtained at the peak amplitude point. Note though, that here we have not selected a particular point according to a characteristic of the EMG trace (as is the case when using the peak), but a particular point in time derived from another parameter — and one with greater stability. The timing of the peak varies with respect to closure timing.

	peak amplitude			closure amplitude		
	mean	*s*	*v*	*mean*	*s*	*v*
p	56.73	6.88	12.13	28.7	6.36	22.16
b	52.48	7.32	13.95	26.9	4.15	15.43

We conclude therefore that Hypothesis 5 is not confirmed by the data: in fact there appears to be less amplitude stability in the *orbicularis oris* EMG at the point o£ closure than at he peak (especially with [p]).

- We are aware that the lower values obtained at closure for amplitude mean increased measurement error: the accuracy was to half a unit. It is quite possible that 13.95 (peak *v* [b]) and 15.43 (closure *v* [b]) do not lend themselves to interesting comparison; but 12.13 and 22.16 could not be the result of such an error.

It is possible to hazard the guess that in fact wide variation occurs in the amount of lip contraction to take account of the previous position of the lips — i.e. if the lips during the previous segment were nearer closure then less contraction would be required. Intuitively we feel such a guess to be in error: the phonological context was kept constant and any such hypothesis would presuppose a chain of error correction during the utterance that must finally prohibit variation (and this does not happen). In any case in this particular experiment we have no way of knowing what the previous state of the lips was.

Turning now to the point of release (fixed as the point in time where a sudden fall in intraoral air pressure began), we note the following data:

Results

	mean amplitude EMG	[linear arbitrary units]		mean *peak* pressure	cm H_2O	
		s	*v*		*s*	*v*
p	13.23	3.0	23	67.8	4.22	6
b	10.48	3.38	32	53.65	4.41	8

where once again we have assumed that peak pressure is achieved immediately prior to release.

We have already shown that the difference between means for [p] and [b] of oral air pressure is significant (Hypothesis 1) and since the point of release might be where there will be most interdependence between *orbicularis oris* contraction and air pressure (since there is the possible hypothesis that at this point the lip closure is permitted to 'give way' to the intraoral air pressure), we might make the following hypothesis:

Hypothesis 6

There is a significant difference between the mean amplitudes of *orbicularis oris* EMG associated with [p] and [b] at the moment of release of the stop: [p] > [b].

Results

	mean	*s*	*v*
p	13.23	3	23
b	10.48	3.38	32

$U = 116.6$

Mean amplitude EMG from *orbicularis oris* at release: arbitrary linear units.

For a two-tailed test *U* must equal or be less than 114 to be significant at the 0.02 level (or one-tailed 0.01 level).

We safely conclude therefore that Hypothesis 6 is supported by the data: mean amplitude of *orbicularis oris* EMG associated with tokens of [p] in this experiment is significantly greater than that associated with tokens of [b]. The ratio is b:p = 1:1.26. We note that this ratio is precisely that obtained for the intraoral air pressure see Hypothesis 1 and conclusions).* [*footnote: We cannot believe that this absolute identity is not coincidence — the data is not that accurate, but we have shown that the ratios are very similar.]

Since intraoral air pressure is greater for [p] than for [b] on average and since we have just seen that EMG amplitude from *orbicularis oris* at the point of release is greater for [p] than for [b] on average and by roughly the same amount — we may now hypothesise as follows:

Hypothesis 7

There is close correlation between the intraoral air pressure and EMG amplitude from *orbicularis oris* at the point of release of the stops [p] and [b].

Results

The Spearman rank correlation coefficient has the following values:

	p	b
rS	0.1872	0.132

neither of these values being significant even at the 0.5 level of confidence. Hypothesis 7 is therefore not supported by the present data.

We are now faced with a very interesting situation: on the one hand oral pressure and EMG amplitude at the moment of release are seen to differ on average by quite similar amounts, and on the other hand no significant correlation can be found between the two parameters within each category — [p] or [b].

We conclude that although at the point contraction (and therefore innervation) of *m. orbicularis oris* differs between [p] and [b] there is no difference within each to support the claim that just enough contraction is being supplied to hold back the air pressure. In fact, as elsewhere (e.g. at the peak of EMG) it would seem that more than enough contraction is supplied. We cannot allow any conclusion therefore which might suggest either on-going feedback between the two parameters or which might suggest that contraction is organised such that it laxes to a critical level at exactly the right time to permit the intraoral air to break through.

Interestingly, now that we have refuted Hypothesis 7, we can see that pooling the data confirms that it is the fact that [p] and [b] are different on the two parameters which is operating, not that individually each token might have displayed a correlation. So, for confirmation:

Hypothesis 8

Considering [p] and [b] pooled together there us a positive correlation between intraoral air pressure and EMG amplitude for *orbicularis oris* at the moment of release (where peak intraoral air pressure is assumed to occur immediately before the release).

Results

	mean	*s*	*v*	*n*
maximum pressure	60.74	8.3	14	40
amplitude EMG at release	11.85	3.92	33	40

$r = +0.4291$

$tr = 2.9286$

Pooled data for [p] and [b] where *r* is the parametric correlation coefficient and *tr* represents the significance (*t*-test tables) of *r*. The positive correlation is significant beyond = 0.01 (two-tailed test).

We would obviously expect a correlation to be shown — but, as mentioned above, this quite simply means that the data is grouping automatically into two sets [p] and [b] — it does not mean there is correlation within the sets.

We are now in a position to conclude that the data presented from this experiment indicates that there is no cause and effect relationship between intraoral air pressure and EMG amplitude associated with the contraction of *m. orbicularis oris* for a bilabial stop at the moment of release. Rather we might hypothesise that the parameters are given different values initially. In other words, it is not the case, we guess, that the specification of a bilabial stop involves a specification of air pressure (perhaps not directly but as the result of sub-glottal pressure plus vocal impedance) and contraction of *orbicularis oris*, the amount of which is to be determined as and when the amount of air pressure is directly sensed by some feedback. It sees to be the case that EMG amplitude and intraoral pressure (at the moment of release) are specified with respect to [p]-ness or [b]-ness but not with respect to each other. Similarly, it seems unlikely that the intraoral air pressure is varied according to feedback about the degree of lip contraction.

Turning now to the durational measurements. Variation in the duration of closure was seen to be relatively small. In our experience, though, variations in duration of the EMG signal are larger, The question arises whether the EMG signal can be broken down on the time axis and the durational variations ascribed to any one particular temporal phase of the gesture.

Firstly we confirm our informal observation concerning variation in the duration of the EMG signal.

Hypothesis 9

Variation in the duration of the EMG signal associated with the contraction of *m. orbicularis oris* to achieve the stop phase of the segments [p] and [b] is similar to the variation in the duration of the resultant stop.

Results

	closure duration csec			EMG duration csec		
	mean	*s*	*v*	*mean*	*s*	*v*
p	12.38	0.76	6.14	28.88	3.53	12.22
b	12.26	0.7	5.72	26.28	2.28	8.68

Values of *v* for the EMG parameter are greater than those for the closure duration. Once again it is possible that larger numbers for the EMG measurements means greater accuracy — but in that case any error here would increase the value of *v* for the closure duration — an error on the right side. The hypothesis that there are similar duration variations for actual closure and the EMG relating directly to that closure is not confirmed. Our informal observation of relative instability in the EMG duration is therefore demonstrated in this experiment.

It is possible to split the EMG signal along the time axis using the moments of closure and release as fixed points. This produces three sections: (a) EMG before closure, (b) EMG during closure (identical in duration, of course, to the closure measurements derived from the air pressure record), and (c) EMG after closure.

Still using *v* as a way of indicating whether or a particular value or set of values attained for a particular parameter is critical, we may hypothesise follows:

Hypothesis 10

Taking the moments of closure of [p] [b] as fixed points, timing of the onset of muscle contraction to achieve closure is critical.

Results

	mean	*s*	*v*
p	5.6	1.45	25.89
b	4.08	0.53	12.99

Duration of EMG prior to closure (csec)

Variation is therefore greater for [p] than [b]: the value of *v* being double for [p] and not particularly small. The idea that there might be a constant period of increase in contraction before closure is achieved is therefore not confirmed.

The fact that the value of *v* should be so different for the two segments is of interest and no immediate explanation is apparent to us — other than the obvious one that lip contraction for [p] and [b] is different on this parameter. Although a side-track from the main line of this paper, we consider it worth taking a look at this finding for a moment because it ads data to the persistent controversy over whether *orbicularis oris* contraction for [p] differs significantly from that for [b].

Hypothesis 11

The duration of *orbicularis oris* contraction before lip closure is no different for [p] and [b]. Or, better perhaps, since we now have our suspicions:

Hypothesis 11a

The duration of *orbicularis oris* contraction before lip closure is different for [p] and [b], where [p] > [b].

Results

	mean	*s*
p	5.6	4.08
b	4.08	0.53

Duration of *orbicularis oris* contraction before closure (csec).

The Mann-Whitney *U*-test gives us a value $U = 50.5$. The critical value for U at = 0.001 is 88 (one-tailed test) and, since < 88, we can safely conclude that there is a significant difference between the moans beyond the 0.001 level of confidence and that contraction associated with lip closure for [p] begins earlier than for [b] on the average. The ratio of duration of EMG preceding closure for [b]:[p] = 1:1.37.

Thus, despite the fact that the duration of EMG activity prior to closure is not particularly stable (less for [p] than [b]), there is a very significant difference between [p] and [b], where [p] > [b]. We do not think that any error in measurement (despite the small values) could have more than slightly emphasised this difference.

Returning now to the question of dividing the EMG signal into three parts in order to examine the source of instability in the durational measurements, we now take a look at that part of the signal occurring after the moment of release when the specification of the segment presumably no longer includes tension in the lips. At this point therefore we might expect considerable variation if we believe that contraction is simply allowed to decline as it will or little variation if we believe that it is important for contraction to cease as soon as possible.

Hypothesis 12

There is more variation in the duration of EMG following release than prior to closure.

Results

	before closure			after closure		
	mean	*s*	*v*	*mean*	*s*	*v*
p	5.6	1.45	25.89	10.95	2.96	27.03
b	4.08	0.53	12.99	9.98	1.87	18.74

EMG from *orbicularis oris:* duration in csec

We observe therefore that there is not particularly more variation in the duration of the EMG from *orbicularis oris* after release than before release. Once again, though, [b] has significantly less variation than [p]. We do not know whether active contraction of the muscle ceases as quickly as possible and do not think our data can indicate this one way or the other, especially since the values of *v* are not very small.* [**footnote:* We must confess, though, that we have only an intuitive idea at this stage as to what constitutes a large and what a small variation. This idea is based, as described earlier, on the fact that variations (particularly durational) appear less for the events resulting from the contraction (e.g. lip contact duration) than for the contraction itself.]

However, we could make the provisional suggestion that as contraction ceases a longer time would be require the greater the peak amplitude reached. There was a slight but insignificant negative correlation between peak amplitude and EMG duration after the release, but what would be ore important would be the correlation between the duration after release and the EMG amplitude at the moment of release.

Hypothesis 13

There is a positive correlation between the amplitude of the EMG signal from *m. orbicularis oris* at the moment of release and the time from this point to the cessation of the EMG signal.

Results

rS ([p]) = +0.2989
rS ([b]) = +0.2485

The significance of these positive correlations is probably not beyond the 0.5 level but they may indicate a trend for relationship between EMG amplitude at the moment of release and the decay time following that moment.

CONCLUSION SUMMARY

We have reached the following provisional conclusions from this experiment involving surface electrode EMG of *m. orbicularis oris* superior and intraoral air pressure during the articulation of the segments [p] and [b] in monosyllable initial position followed similarly by a long stressed mid-central vowel:

- A significantly greater peak intraoral air pressure is reached for [p] than for [b] during the stop phase of the segments (b:p = 1:1.26).

- There is no significant difference in peak amplitude reached by the EMG signal associated with *orbicularis oris* contraction for lip closure between [p] and [b].
- There is no significant correlation between peak intraoral air pressure and peak EMG signal amplitude associated with the *orbicularis oris* contraction principal in supporting that pressure.
- There is a relative stability in the duration of the closure of the lips during [p] and [b] in this sample.
- There is no less variation in EMG amplitude either at the moment of closure than in the peak amplitude, or at the moment of release.
- There is significantly greater EMG amplitude at the moment of release for [p] than for [b] (b:p = 1:1.26).
- There is no significant correlation between intraoral air pressure and EMG amplitude at the moment of release of stops [p] and [b].
- Pooled data from [p] and [b] show a significant positive correlation between intraoral air pressure and EMG amplitude at the moment of release.
- Variation in duration of closure is less great than variation in the duration of EMG associated with the contraction of *m. orbicularis oris* to achieve that closure.
- Timing of the onset of *orbicularis oris* contraction to achieve closure does not seem to be critical within each of [p] or [b].
- The duration of *orbicularis oris* contraction before lip closure is greater for [p] than [b], where the ratio [b]:[p] = 1:1.37.
- There is slightly greater variation in this sample) of EMG duration following release than preceding closure
- There is a slight positive correlation between the amplitude of the EMG signal at the moment of release and the duration of the EMG signal following the release.

Most of our conclusions are about the means obtained from the sample of twenty repetitions of each of the two utterances. The non-parametric statistics used are quite adequate for a sample of this size. All conclusions relate to the performance of one subject employing British English pronunciation and may or may not be generalisable: but we are not contributing to the much rehearsed one-or-many-subjects argument. Our purpose has been to discover something about consistency within one speaker's articulations.

- *NOTE:* There is much precedent for employing an averaging technique with electro-physiological data of this nature. What happens on any one occasion may be unimportant compared with general trends which emerge from a statistical treatment of several samples. The technique is now well-established in the interpretation of certain types of evoked response cortical potentials, where, were it not for the fact that in this way significant patterns emerge from apparently (but wrongly designated) random signals, much useful information would be discarded.

APPENDIX I

a. Raw data from 'purr'

	A1	A2	A3	A4		D1	D2	D3	D4
1	65.5	52	28	17		30	13	5	12
2	71	69.5	38	11.5		29	13	6.5	9.5
3	66	57	29.5	13.5		28.5	13	5	10.5
4	67.5	56	27.5	18		32	13	7	12
5	69	53.5	28	13.5		27.5	13.5	6.5	8.5

6	63	67.5	39	8		30.5	13	8	9.5
7	65	68	38	17		27	11.5	4.5	11
8	77	64	28	7		28.5	12.5	5	11
9	74	56	33	22		27	11	6	10
10	73	52	28	16		32	11.5	5.5	15
11	76	54	22	18.5		28	12	5.5	10.5
12	66.5	53	36	8.5		29	11.5	6.5	11
13	66	49.5	31	12		28	13.5	5	9.5
14	66.5	51	19	10.5		27	12.5	4	10.5
15	67.5	61	22	8		27	12	4	11
16	65.5	47	29	13		27	12.5	6.5	8
17	65	67.5	36	12.5		27.5	12	5.5	10
18	68	48.5	18	15		32	12.5	7.5	22
19	60.5	51.5	24	14.5		24.5	11	4	9.5
20	64	56	20	8.5		25.5	13	4.5	8

b. Raw data from ‘burr’

	A1	A2	A3	A4		D1	D2	D3	D4
1	58	39	27	8		26.5	13	4	9.5
2	62.5	44.5	27.5	17.5		30	12.5	4.5	12
3	56.5	55.5	34	11		27	12	4	11
4	54	46	24	13		23.5	13	4	6.5
5	59.5	59.5	27	11		27	13	4	10
6	58	56.5	33	19.5		32	12	4.5	15.5
7	48	46	32	7.5		28	13.5	4.5	10
8	55	56.5	25.5	9		27	12	5	10
9	50	55	23	11		27.5	13	4	10.5
10	50	55.5	26.5	11		24.5	12	3.5	9
11	53	48	29	7.5		25	11	4	8
12	44	59.5	31	11.5		25.5	12	3.5	10
13	56	62	27	10.5		27.5	12	5	10.5
14	48	55	27	11		24.5	12	4	8.5
15	54	48	20	12.5		24.5	12.5	3.5	8.5
16	48.5	62.5	26.5	8.5		23	11	3	9
17	54.5	35	20	5		26	12	4	10
18	52	55	19	9.5		28.5	13	3.5	12
19	56	52	27	7		26	12	5	9
20	55.5	59	32	8		24	11	4	9

A1 — Intraoral air pressure at moment of release: mm.H2O

A2 — Peak amplitude of EMG: linear arbitrary units

A3 — amplitude of EMG at moment of closure: arbitrary units

A4 — Amplitude of EMG at moment of release: arbitrary units

D1 — Duration of EMG: csec

D2 — Duration of closure: csec

D3 — Duration of EMG before closure: csec

D4 — Duration of EMG after release: csec

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