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EMG INVESTIGATION OF LABIAL ARTICULATIONS

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Results of electromyography with hooked-wire electrodes in one subject in a large number of articulations involving the lips are presented. Stops, pulmonic and glottalic, oral and nasal; fricatives, approximants; rounded vowels; some labials produced by assimilation in English are discussed.

I. INTRODUCTION

In 1974 I was hospitably included in a large programme of electromyography being conducted at the Institute of Phonetics at the University of Copenhagen. Dr. Hajime Hirose placed hooked-wire electrodes in my upper lip, in Orbicularis Oris Superior (OOS) at the vermilion border about 2 cm from the center, in the lower lip in Orbicularis Oris Inferior (OOI) similarly, and in Depressor Labii Inferioris (DLI) about 2 cm below the vermilion border and 3 cm away from the center.

The material consisted mainly of nonsense words with labial consonants between [i-i] or [u-u] (for implosives and ejectives also [a-a]) with stress on the second syllable, e.g. [i'bi], and a number of real words, all said in the frame "Say ... again". The list was read ten times. The sounds occurring in American English were pronounced in my normal pronunciation, i.e. [p] was aspirated and [b] was voiced in medial position, while sounds not part of the English sound system were pronounced on the basis of my general phonetic training (UC London).

The EMG signals and the audio signals were recorded on a professional DC tape recorder. Mingograms containing raw and integrated EMG signals, duplex oscillograms and intensity curves were produced for inspection and for placing the line-up point for averaging. The EMG signals, particularly those of OOI, contained a number of (relatively weak) artefacts.

Filtering experiments showed that almost all artefacts could be removed by means of HP filtering at 390 Hz without distorting the relevant signal, which remained relatively unchanged up to HP 1500, although it was somewhat weakened at higher frequencies (cf. Rischel and Hutters 1980, p. 306-308).

After integration (25 ms) and HP filtering (390 Hz) the EMG signals were fed into a PDP-8 computer together with an intensity curve and an F_0 curve. After control of the print-outs of the sampled signals, the EMG curves were averaged. The Figures are somewhat reduced copies of these print-outs. The standard deviation in percent of the mean is shown below the EMG curves. In most cases the boundary between the first vowel (of the nonsense word) and the consonant was chosen as the line-up point for the averaging. This boundary was identified by the abrupt decrease in intensity.

The indication of the "text" below the individual curves in the figures is not in phonetic transcription but in an arbitrary orthography for the use of the computer, e.g. IPI= [iphi], IPHI= [iɸi]. The phonetic transcription which is given at the bottom of the pages is in IPA, with the additional diacritic [̢] below a symbol (β̢ ɹ̢) to indicate approximants.

II. COMPARISON OF [p b m p' ɓ]

All show some activity in DLI at the implosion. In the type V'CV this activity is, however, always less than the activity found at the release (see Figures 1, 2, 4, 5). In "capable" [keipəbəl] and "probable" [pɹɑbəbel] DLI has more activity at the implosion than at the release of medial, unstressed [p] and [b], respectively (see Figures 13, 14).

Activity in DLI at the point of closure was also found by Fischer-Jørgensen and Hirose (1974) for three out of five subjects, for one of them only before unrounded vowels. Hadding et al. (1969) say, "Hirano reports that contrary to his expectation from reading the literature, DLI may be involved in the lip-closing gesture" and "Later findings indicate that some speakers normally activate the depressor when articulating labial stops".

Action in OOS and OOI begins about 15 cs before the implosion for [p b m]. The duration of activity for these is presumably related to the speaker's language, American English. Action for [p'] and [ɓ] is rather short in the [a-a] context.

Relative amounts of activity (see Figures 1 and 2):

before i		before u	
OOS	m>b>p	OOS	m>b>p
OOI	m>p>b	OOI	m>b>p
DLI		DLI	
at implosion	p>m>b	at implosion	b>m>p
at release	m>b>p	at release	m>b>p

[m] clearly has higher activity than [p], and this is significant in OOS, and for OOI in the [u-u] context, and probably also in the other cases. With a few exceptions (OOI in the [i-i] context and DLI at the implosion) [m] has more activity than [b] and [b] more than [p], but these differences are rarely significant. These judgments are based partly on an inspection of the overlappings of the ten individual curves, and partly on the differences in millivolts compared to the standard deviation. The differences were measured in millimeters and converted to millivolts; the scale was not large enough for precise measurements.

One can conclude that in this speaker [m] always has relatively more activity than [b] and [p] (and the difference from [p] is almost always significant) and [b] tends to have higher activity than [p]. This is evidence against the assumption that the strength of the activity in the lips depends on the intra-oral pressure; [p] should require more effort to keep the lips closed against the higher air pressure behind the closure.

Öhman et al. (1966): "...the voiceless stop...has a higher intraoral pressure than the voiced cognate. This higher pressure must be counteracted by a more energetic implosion gesture. At the release, however, the separation of the lips is aided by the intraoral pressure so that in this phase of the consonant the muscular activity does not have to be as energetic in the voiceless as in the voiced case."

The results in the present material agree with the conclusions of Fischer-Jørgensen and Hirose (1974) and Tatham and Morton (1973) that the activity in the closing muscles is in no way related to the intra-oral air pressure. Malécot and Richman's observation (1974) is of interest here: "We now consider force of articulation to be based on a synesthetic interpretation of intra-buccal air-pressure."

The relations between [p] and [b] are of interest for the fortis-lenis question. Perrin and Sharf (1970) (quoted in Tatham and Morton 1973) "...obtained results indicating greater EMG peak amplitude for [p] than for [b]." Most investigators have found no consistent difference.

Lysaught et al. (1961): "The electromyographic measures showed no significant difference in timing or amount of muscle activity at the lips between /p/ and /b/."

Harris et al. (1965): "[There is a] slight average tendency for "tense" sounds to be produced more forcefully than "lax", but this tendency is present only in some subjects and when large numbers of responses are averaged." "Differences exist on the average, but they are small at best and non-existent for some subjects." "The differences observed [between /p/ and /b/] ...could not serve as a basis for a workable phonemic distinction based on muscular tension or laxness."

Fromkin (1966): "Since the articulation of /p/ does not in any way show consistently greater muscular activity of the orbicularis oris muscle than the articulation of /b/, it can be concluded that a feature other than the tense-lax feature must differentiate these two phonemes in American English."

Lubker and Parris (1970): "The labial gesture for the phone types /p/ and /b/ is essentially monotypic, requiring no more forceful labial contact or EMG activity for one than for the other."

Tatham and Morton (1973): "[The] difference between the peak amplitude of EMG from Orbicularis Oris associated with [p] and [b] is statistically insignificant at the 5% level."

Gatehouse and Kelman (1976): "[There is] no reliably consistent discrimination between /p/ and /b/."

Studies which distinguish between activity for implosion and for release have found no difference, or slightly greater activity for [b] at the release: Harris et al. (1965): "The difference between /p/ and /b/ is not significant for the lip-opening gesture."

Öhman (1968): "...the release command is usually stronger in /b/ than in /p/."

Fischer-Jørgensen and Hirose (1974): "As for the closing muscles, ...EFJ has a clear tendency to more activity for b. In ten of twelve pairs b has a higher maximum of activity in OOS, and in nine of twelve pairs in OOI. All exceptions are in unstressed position... Only three pairs in stressed position have a significant difference (5% level), but the number of pairs showing the same difference cannot be accidental. Moreover, the activity for b is normally of a slightly longer duration, which fits well with the longer closure time. But none of the other subjects has a clear difference between p and b. The number of individual means having higher activity for p or for b is about equal, and the differences are small." "On the whole, it must be said that the maxima are rather variable, but four of the six subjects have a clear tendency to stronger activity for b than for p at the release.

On all consonants with labial closure, OOS shows more activity than OOI. This might, of course, be due to accidents of the placement of the electrodes, but a comparison with the rounded vowels shows that in vowel rounding there is practically no difference between OOS and OOI. Thus OOS is relatively more important for closures.

This is also apparent from [u-u] items: OOS is always higher at the implosion of the stop than for the rounding of the preceding vowel, while for OOI there is hardly any difference. The following vowel [u] has lower activity than the consonant for both OOS and OOI, but this may be because the activity is high in the consonant, and keeping the rounding after a closure does not require so much activity. Cf. Leanderson et al. (1971), who found that "the degree of motor activity in a muscle used for the production of a certain speech sound was strongly dependent on how much that muscle was activated during the preceding sound."

[upu], [ubu] and [uwu] (Figures 2 and 10) show three peaks in OOS and OOI, the peak for the consonant being the highest in OOS, and the peak for the second [u] (though this is the stressed one) being considerably lower for both muscles than the first one.

If the sequences [ˈ--pəb--] of "capable" and [ˈ--bəb--] of "probable" (unstressed) are compared, we find that OOS and OOI have lower peaks for the second labial (Figures 13 and 14).

In [ip'i] and [iɓi], [p'] has higher peaks in all three muscles: in [ap'a] and [aɓa] the same relation holds, except that [p'] = [ɓ] in DLI (Figures 3 and 4).

I had thought that DLI might show more action in getting from lip-closure to an open vowel [a] than in getting to a close vowel [i], but the amount of action is the same in DLI in [ip'i] and [ap'a], and in [iɓi] and [aɓa]. Fischer-Jørgensen and Hirose (1974) found that "most of the subjects have a tendency to stronger activity of DLI before a than before i."

There is a great deal more activity in DLI before unrounded vowels, where DLI is involved in opening and spreading the lips, than before rounded vowels (the lips remain rounded during the closure) (cp. Figures 1 and 2). Fischer-Jørgensen and Hirose (1974) point out that in their Danish subjects DLI has very little activity (or none at all) for the opening of stops before [u], except for one subject out of five.

III. COMPARISON OF STOPS, FRICATIVES AND APPROXIMANTS

One thinks of fricatives as requiring a "nicer" adjustment of the articulators to arrange the position where friction will be produced, and hold it.

In Hardcastle (1976) we find a clear statement of this view: "In general terms, then, fricatives can be said to require more delicate neuro-muscular control than stops" ... "The categories stop and fricative for example can be differentiated with reference to the type of muscular activity employed in their articulation. For the production of a stop, a ballistic type of muscular contraction is necessary, i.e. one involving primarily protagonist muscles operating relatively independently of antagonist muscles." ... "A fricative, on the other hand, requires a far more delicate balance of protagonist and antagonist muscles to create the specific stricture required to maintain the turbulent flow of air necessary for its production.

In the sets [p ɸ] and [b β β̞] (Figures 5 and 6) there is less action in OOS and OOI for the fricatives than for the stops, and less still for the approximant [β̞]. It looks as though it is the activity for the distance over which the lips move that is being recorded, rather than tension. There is also much less action in the antagonist DLI for the fricatives and approximant than for the stops. The stops seem to have more controlled movement of protagonist and antagonist than the fricatives, but other muscles may also be involved, and the problem is very complicated.

The fricatives which have their main narrowing at the lips, [ɸ β], have more activity in OOS than in OOI, like the stops (Figures 5 and 6). In those fricatives which have their main place of articulation elsewhere but have rounding additionally [ʃ dʒ ɹ̝] (Figures 7, 8, 9), we find that between [i-i] OOI is appreciably higher than OOS, just the opposite of the case of the mainly labial sounds. In the [u-u] context, these fricatives often have a valley in OOS for the consonant, but not in OOI; that is, OOS is less active for consonant- than for vowel-rounding. In the [u-u] context, the approximant [w] has a peak in OOS in the consonant compared to the vowels (Figure 10), but this is not the case in [uɸu] (Figure 11), [uβu] and [uβ̞u]. The labio-dental fricatives, [f] (Figure 12) and [v] have, of course, more activity in the lower lip.

There are also differences in timing between the various types of consonant, which can be seen most clearly in the [i-i] context (see Figures 1 and 3). For consonants with bilabial closure the peak in OOS and OOI is approximately at the moment of implosion. The activity starts about 16-20 cs earlier, rather slowly at the beginning. Only [iɓi] starts later (OOS 7 cs, OOI 12 cs). The fall is abrupt and the zero line is generally reached about 8-9 cs after the peak.

Where lip activity is a secondary articulation (see Figures 7, 8, 9, [i-i] context), the activity starts earlier, 23-34 cs before the line-up point (which is the beginning of the abrupt fall in the intensity curve) and the peak is also much earlier, 10-20 cs before the line-up point. The rise and fall are rather symmetrical.

[iwi] (Figure 10) looks very much like the plosives, but in [iɸi], [iβi], [iβ̞i] (Figures 5 and 6) OOS, but not OOI, starts later, about 12-15 cs before the line-up point. In OOI the activity starts 18-20 cs before the line-up point, as for the plosives, but the peak is 8-9 cs earlier, and the fall continues until 10-20 cs after the line-up point. These consonants therefore have a more rapid rise than fall in the closing muscles.

IV. SOME LABIALS PRODUCED BY ASSIMILATION

In English (and Danish) [ə] is frequently represented by a syllabic consonant of the same place of articulation as a following consonant, particularly when the possible [ə] comes between two consonants of the same place of articulation, e.g. "back again", "all alone", "on a national basis", "rather than": ['bækg̩gɛn] ['ɔll̩'loɷn] [ɒnn̩'næʃnəl 'beɪsɪs] ['rɑðð̩ðən].

I was curious to know whether such syllabic consonants would be articulated with a separate burst of muscular energy. I looked at

'keɪpəbəl 'keɪpb̩bəl

'prɑbəbəl 'prɑbb̩bəl

and also cases with [m] and [v]. In the assimilated cases there are peaks in OOS and OOI for the implosion of the long labial articulations, and then a continuous very slight action until the release of the closure, but nothing that could be described as separate peaks for the syllabic consonants representing [ə] (see Figures 13 and 14).

V. VOWELS

Of the series <u>who'd</u>, <u>hood</u>, <u>hoed</u>, <u>hawed</u> [hɔɪd] and <u>how'd</u>, only <u>who'd</u> [hu:d], <u>[hɔɪd]</u> and <u>how'd</u> [haud] are presented (Figures 15, 16, 17). In all the rounded vowels the amount of activity is very similar in OOS and OOI. Fischer-Jørgensen and Hirose (1974), however, found that in their material "the dominating muscle for rounding seems to be OOI", and three out of four subjects hardly used OOS in rounding.

In the monophthongs, action in OOS and OOI decreases throughout the vowels and stops at the closure for [d]. For [oɷ] it increases in OOS and decreases in OOI. The increase is presumably because [oɷ] is a "closing" diphthong and the rounding increases as the vowel becomes closer. We transcribe this end of the diphthong with the symbol [ɷ], but this does not mean that it necessarily has the quality or the rounding of the monophthong [ɷ], but merely that the movement is towards a closer vowel. I can suggest no reason why the activity should <u>decrease</u> in OOI.

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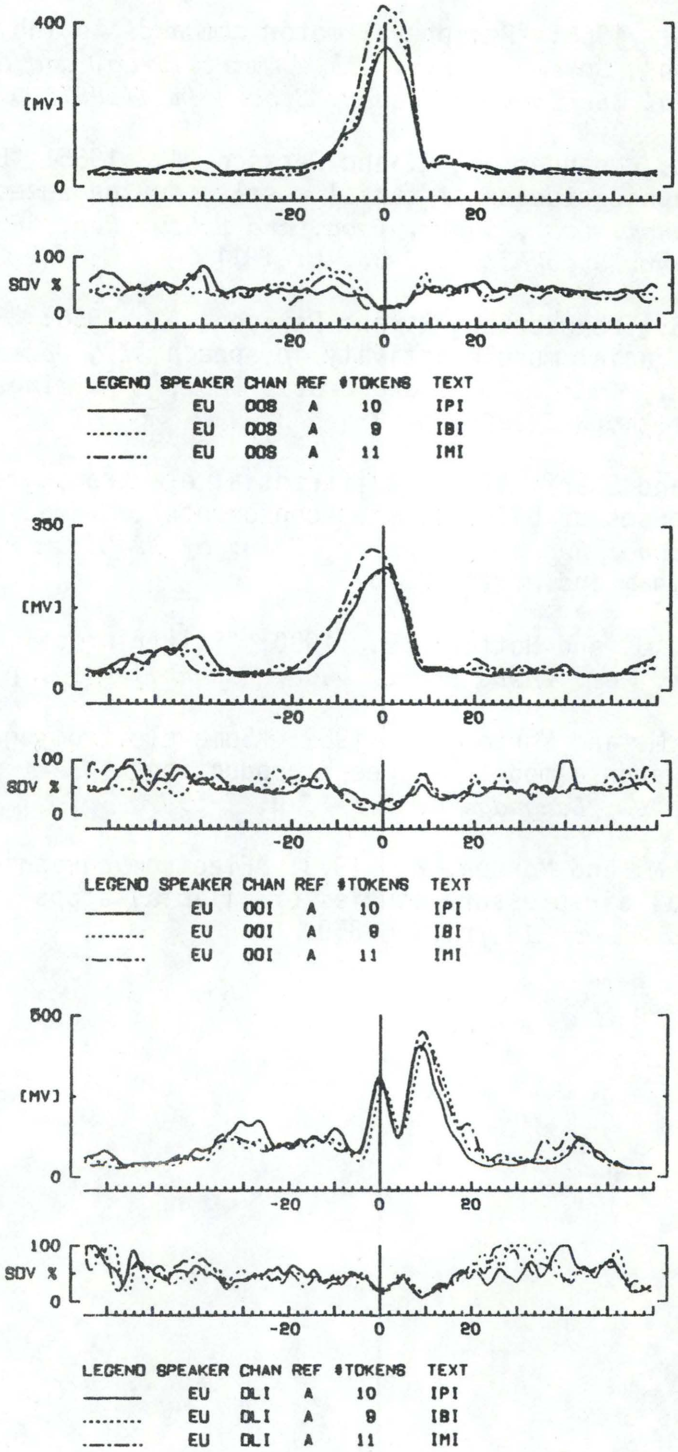

Figure 1

[iphi] ———, [ibi] ·····, [imi] -·-·-·-·

Average curves.

CHAN: *channel = muscle (OOS, OOI, DLI)*

REF: *line-up point = start of intervocalic consonant (valid for Figures 1-7 and 9-14).*

TEXT: *not phonetic transcription but an orthography for the use of the computer.*

SDV %: *standard deviation in percent of mean.*

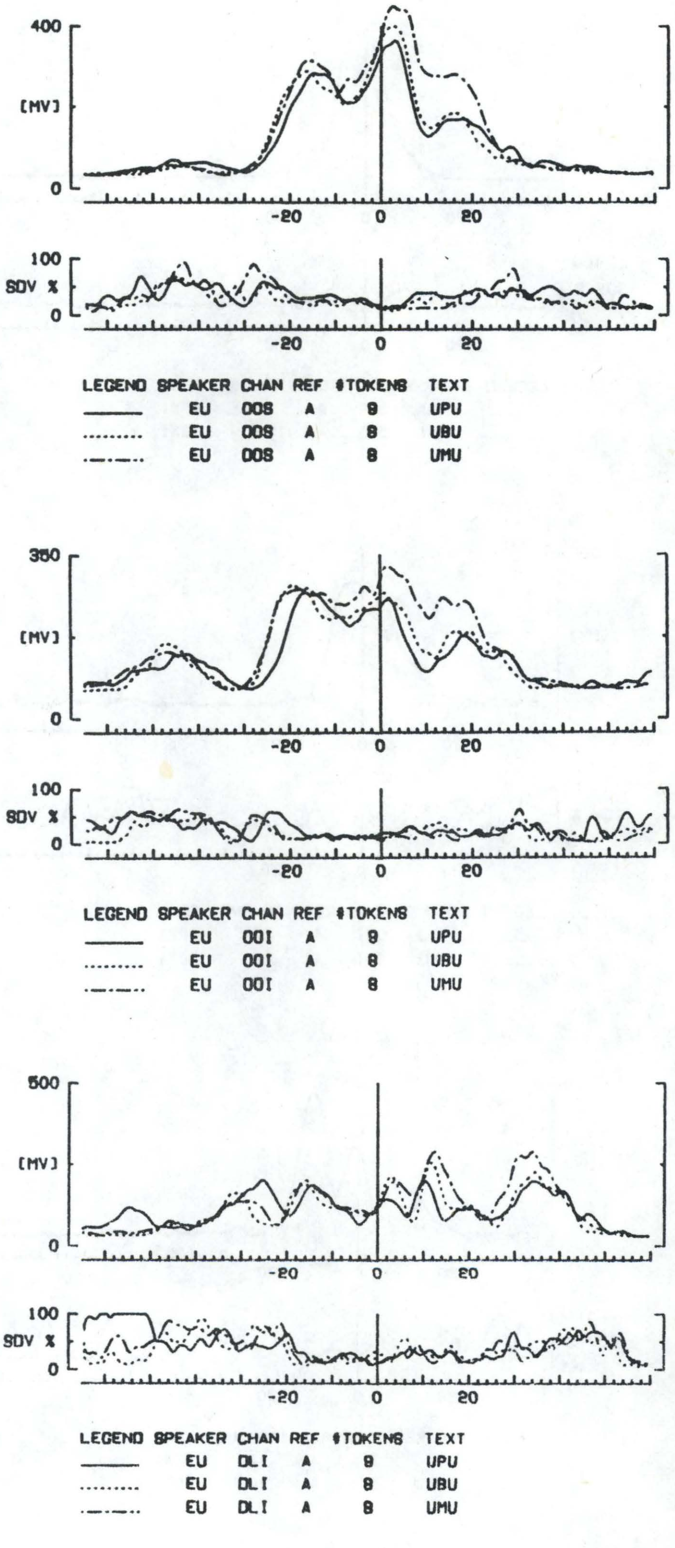

Figure 2

[uphu] ——— , [ubu] ····· , [umu] -·-·-·-

(see further legend to Figure 1)

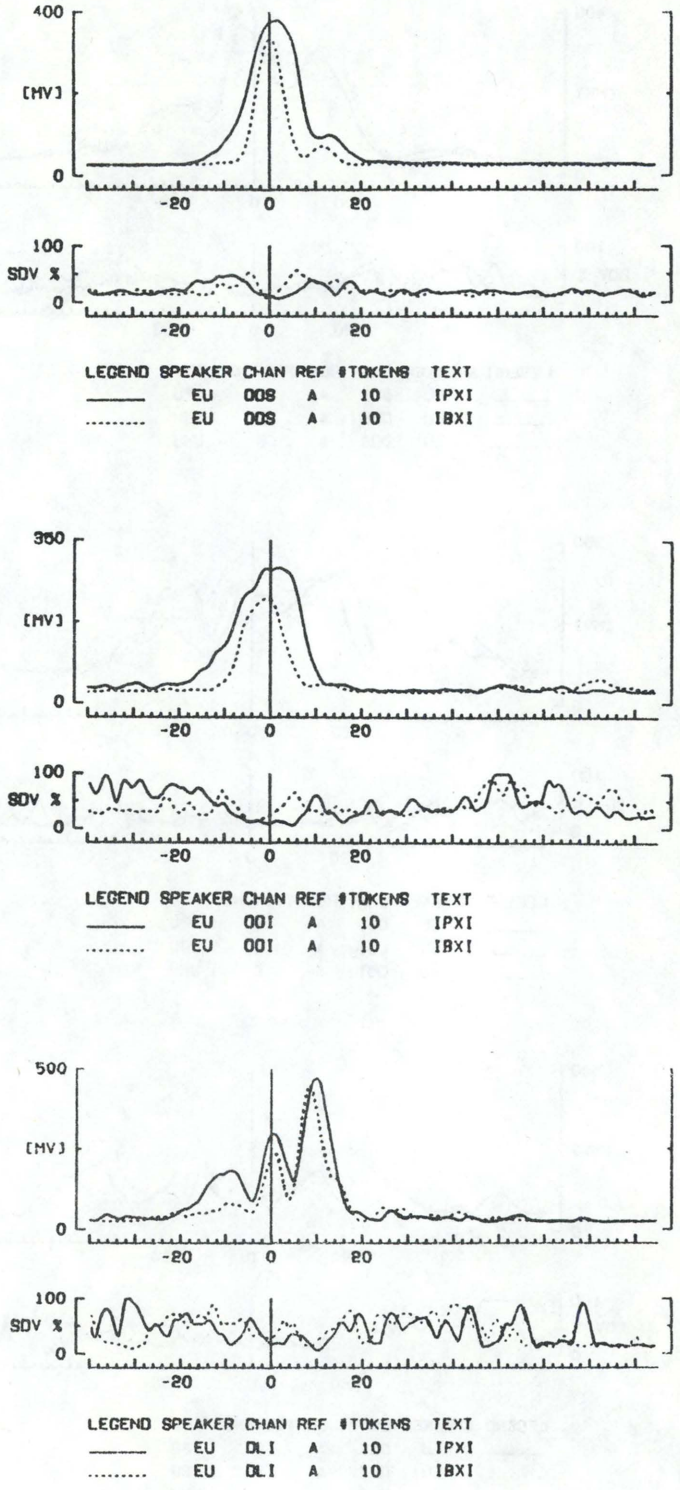

Figure 3

[ip'i] ———— , [iɓi] .....

(see further legend to Figure 1)

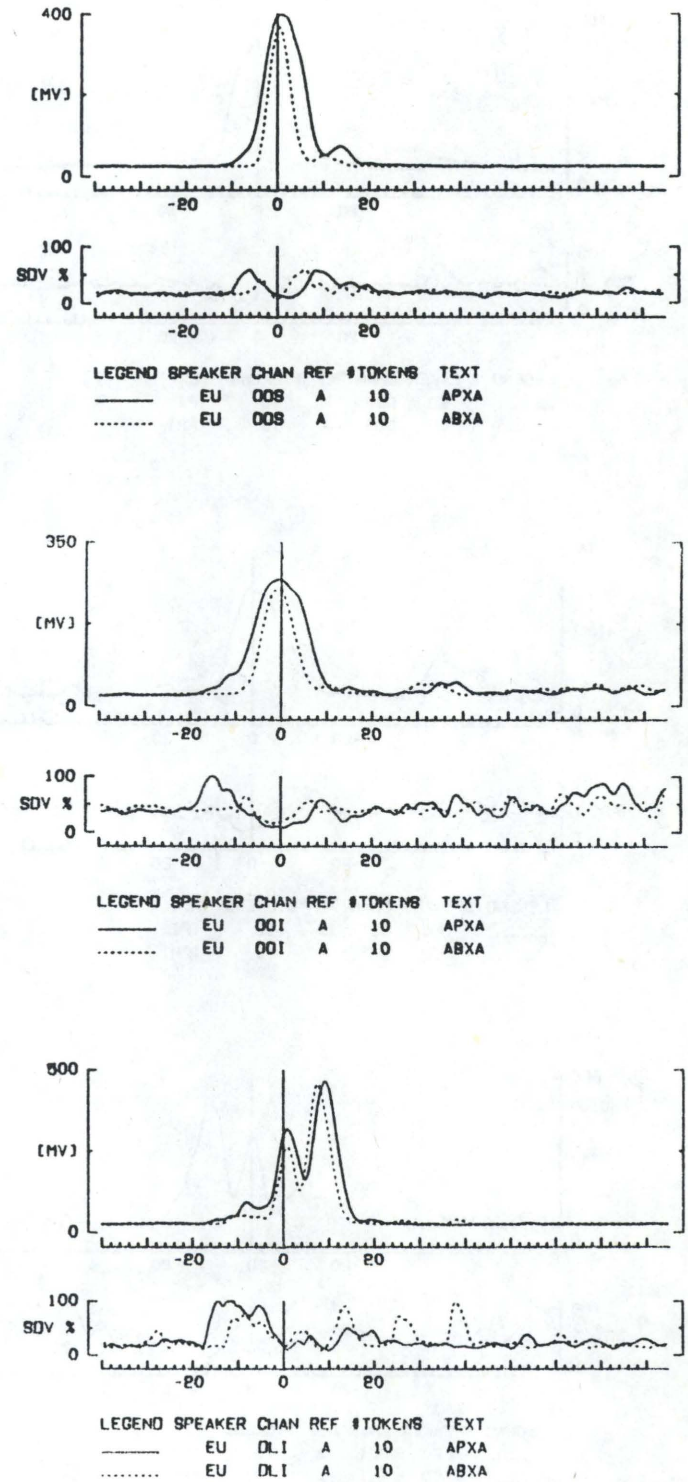

Figure 4

[ap'a] ——— , [aɓa] .....

(see further legend to Figure 1)

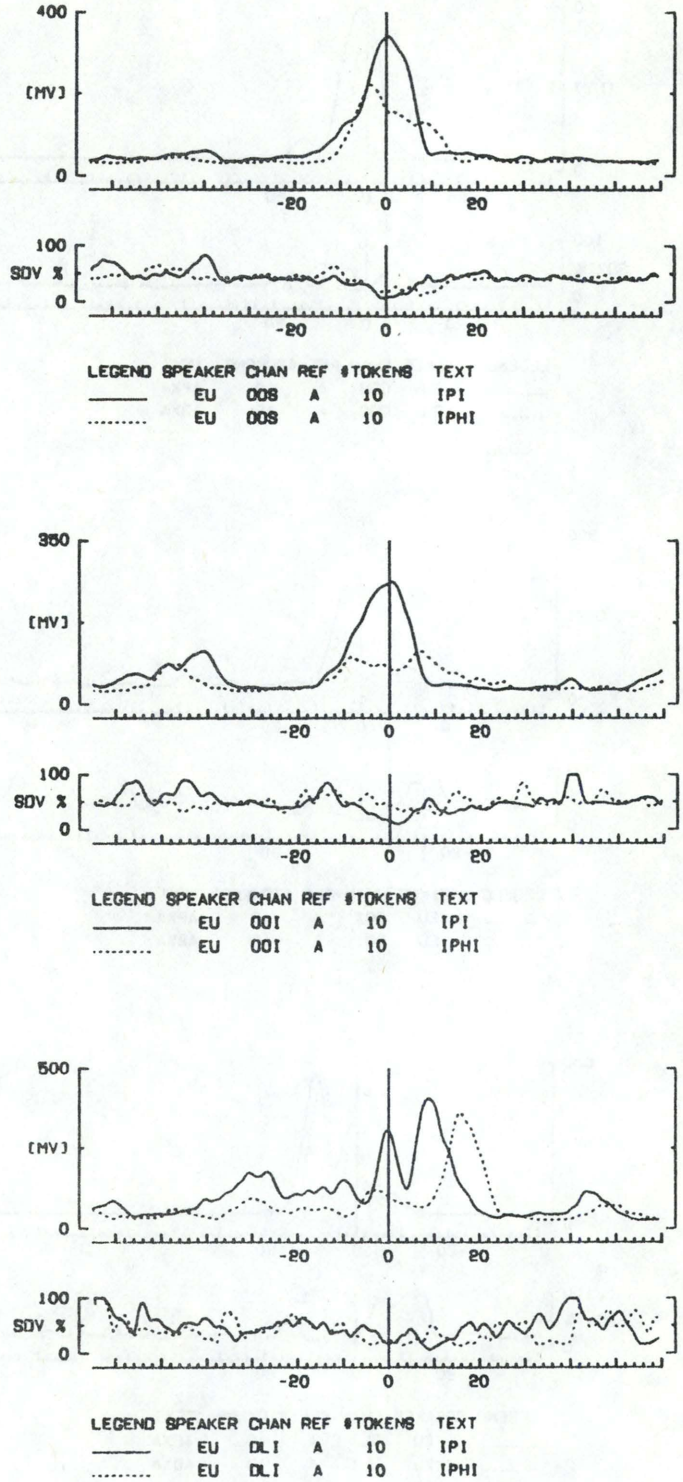

Figure 5

[iphi] ——— , [iɸi] · · · · ·

(see further legend to Figure 1)

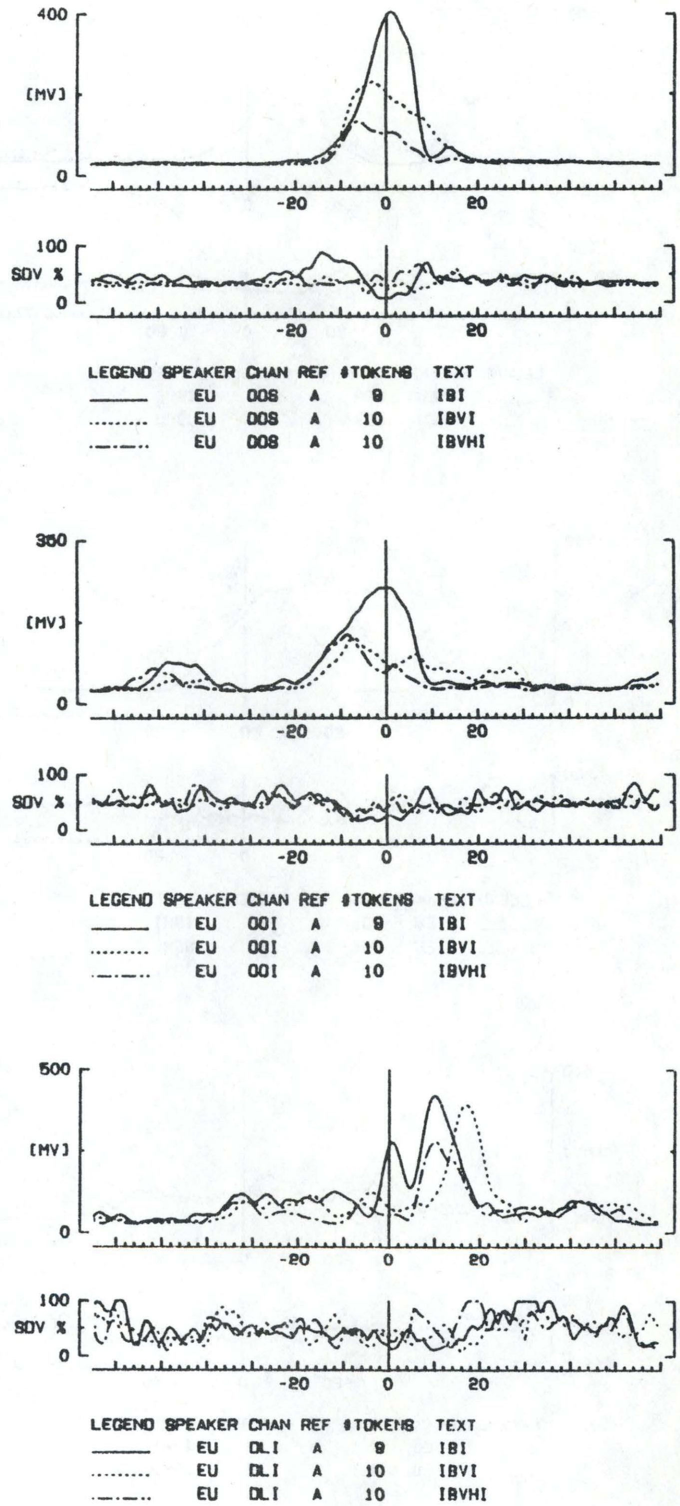

Figure 6

[ibi] ——— , [iβi] ····· , [iβ̞i] -·-·-·-

(see further legend to Figure 1)

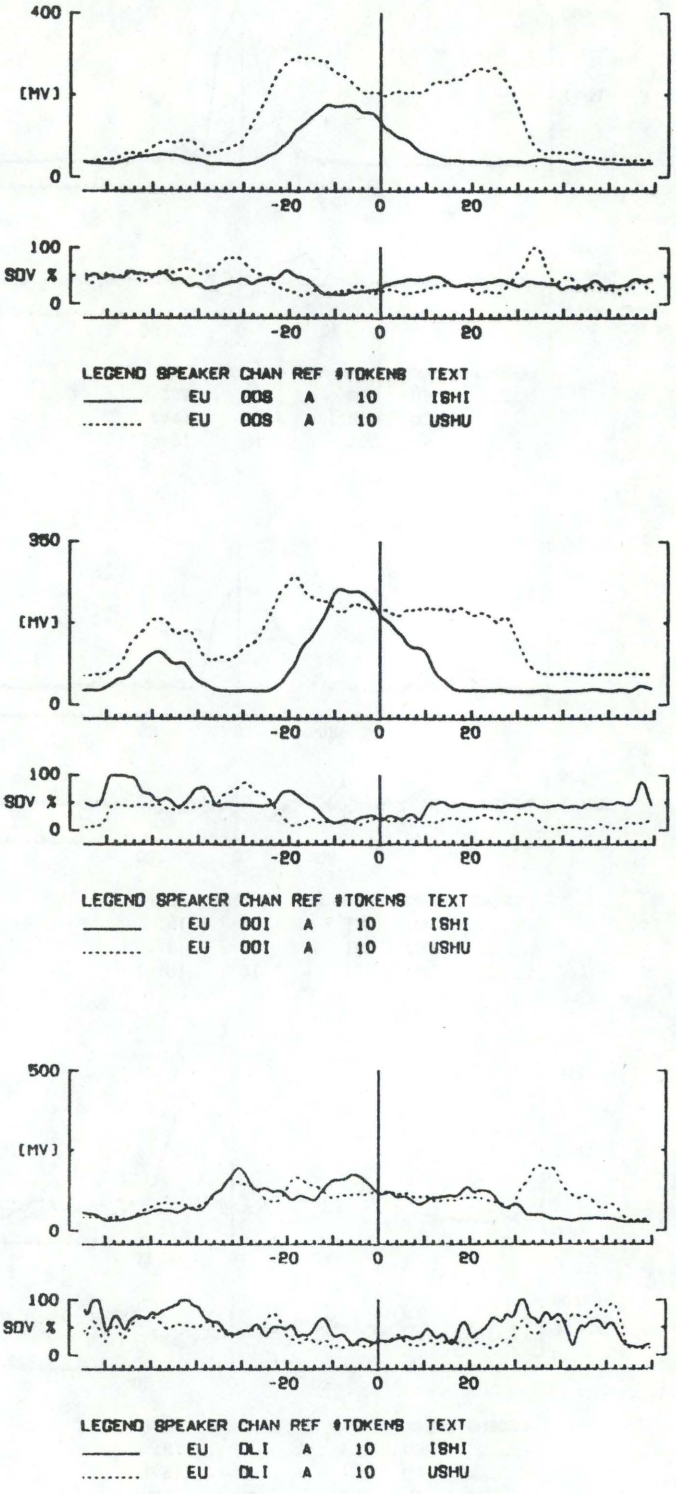

Figure 7

[iʃi] ———, [uʃu] ·····

(see further legend to Figure 1)

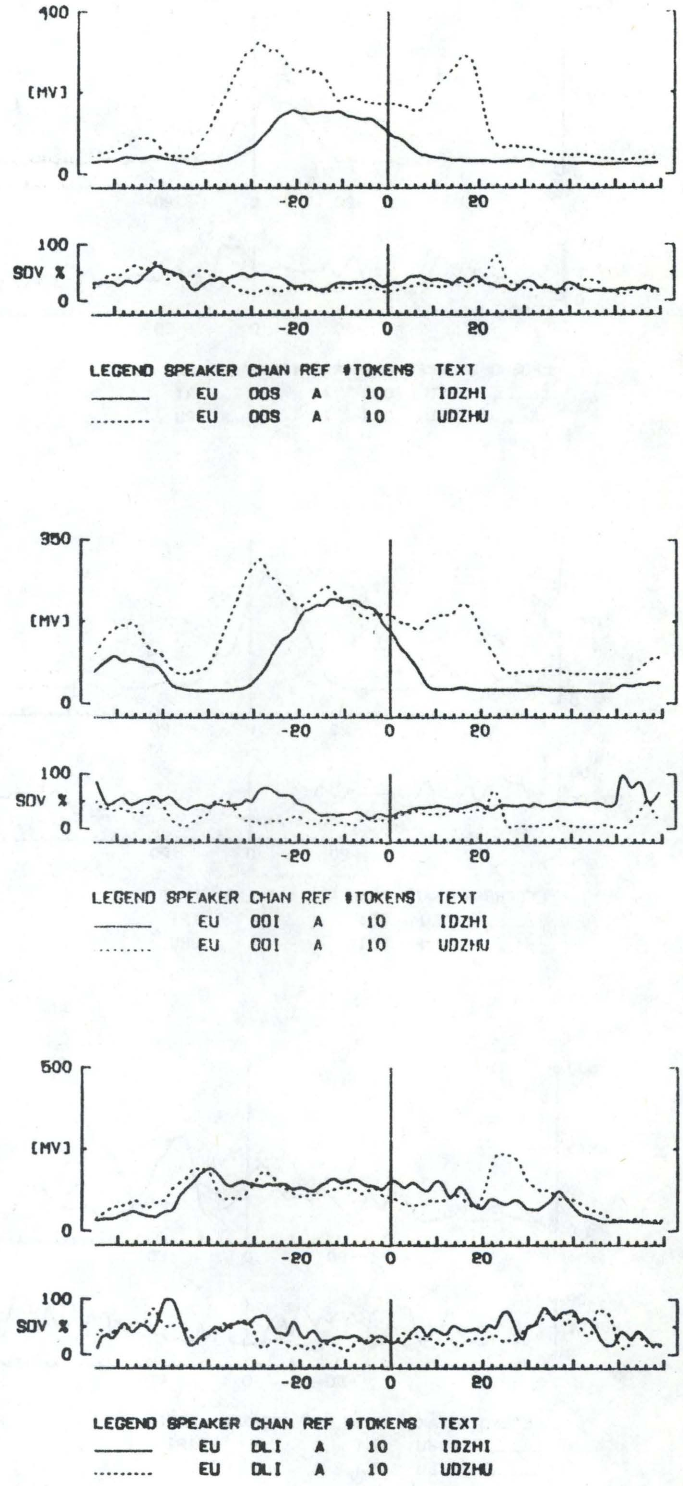

Figure 8

[idʒi] ——— , [udʒu] ·····

line-up point: release of [d]
(see further legend to Figure 1)

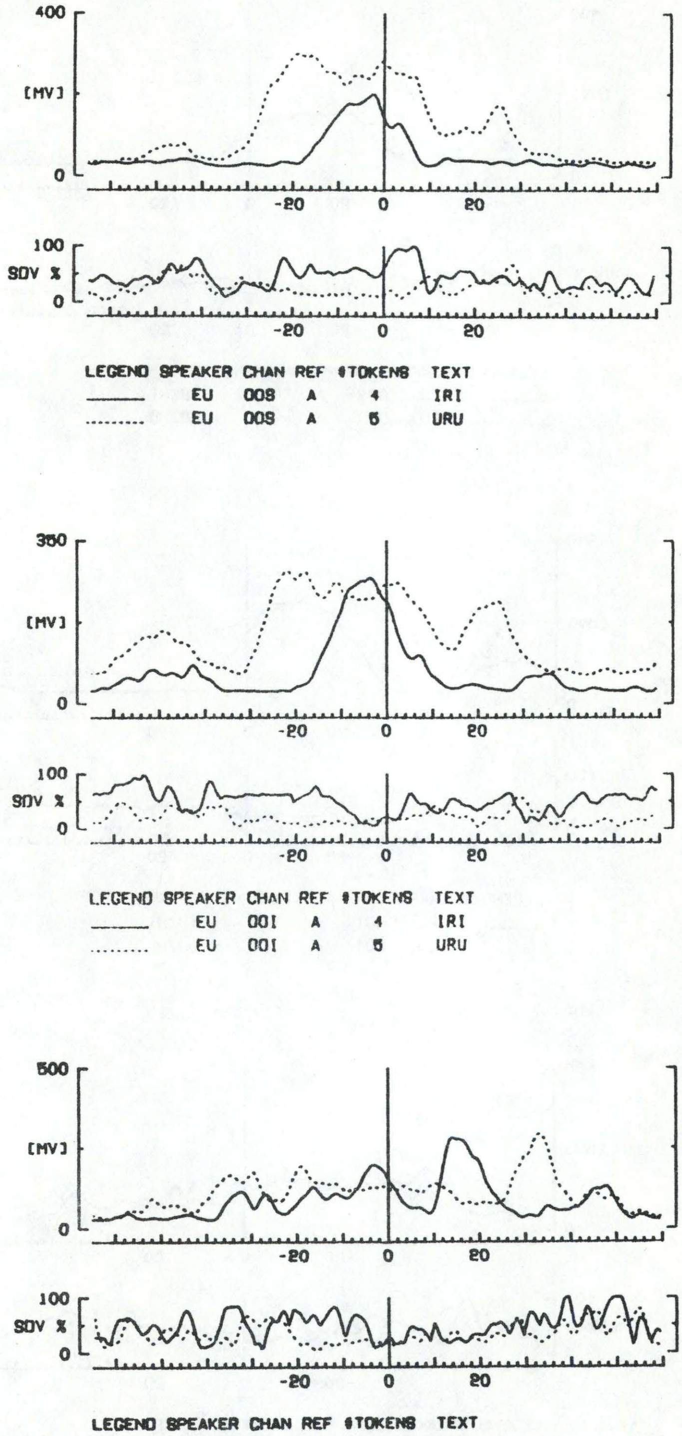

Figure 9

[iɽi] ——— , [uɽu] ·····

(see further legend to Figure 1)

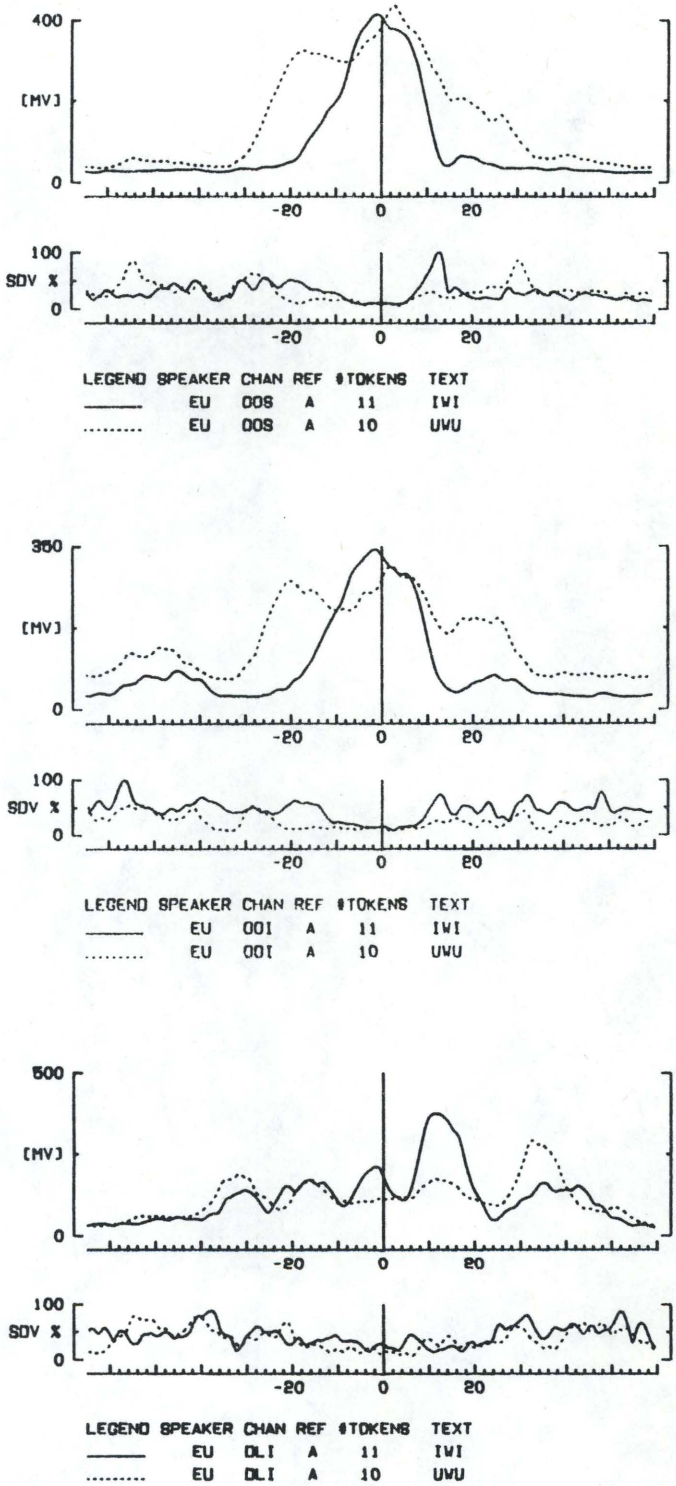

Figure 10

[iwi] ——— , [uwu] ·····

(see further legend to Figure 1)

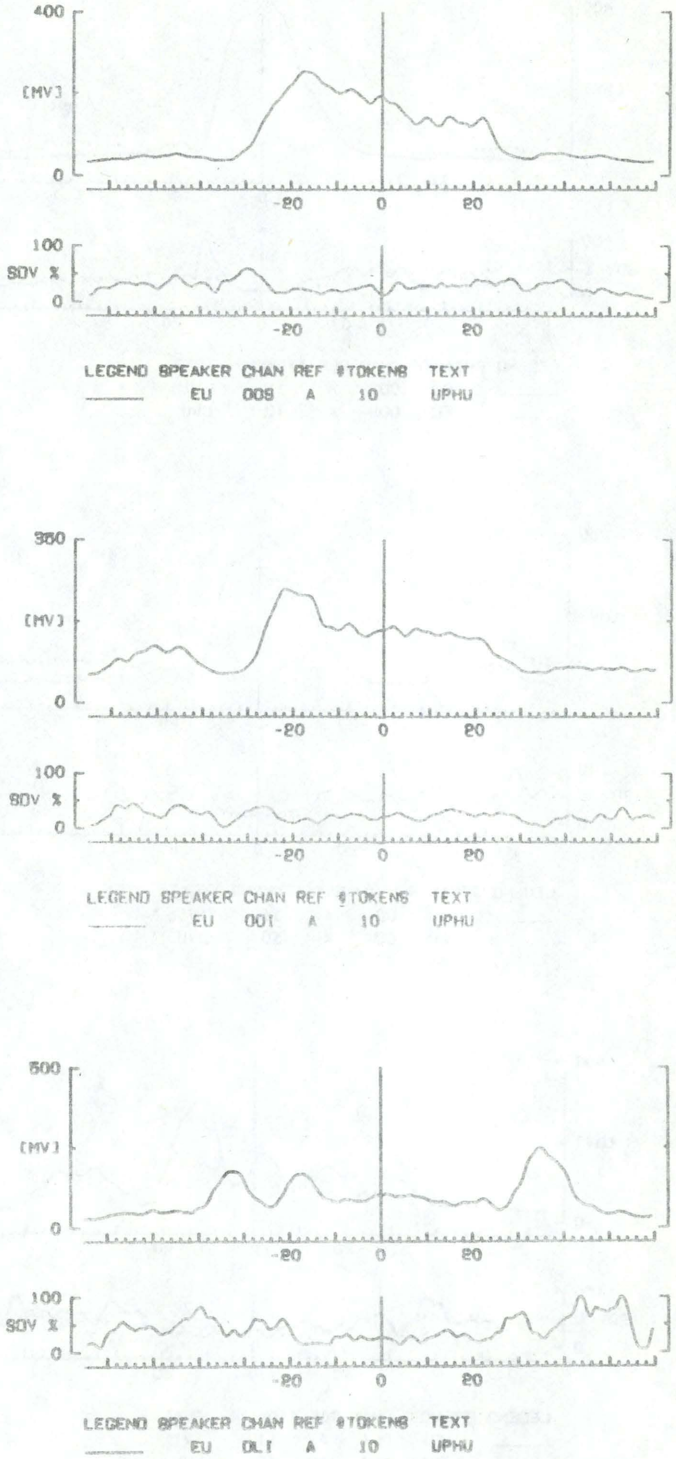

Figure 11

[uɸu]

(see further legend to Figure 1)

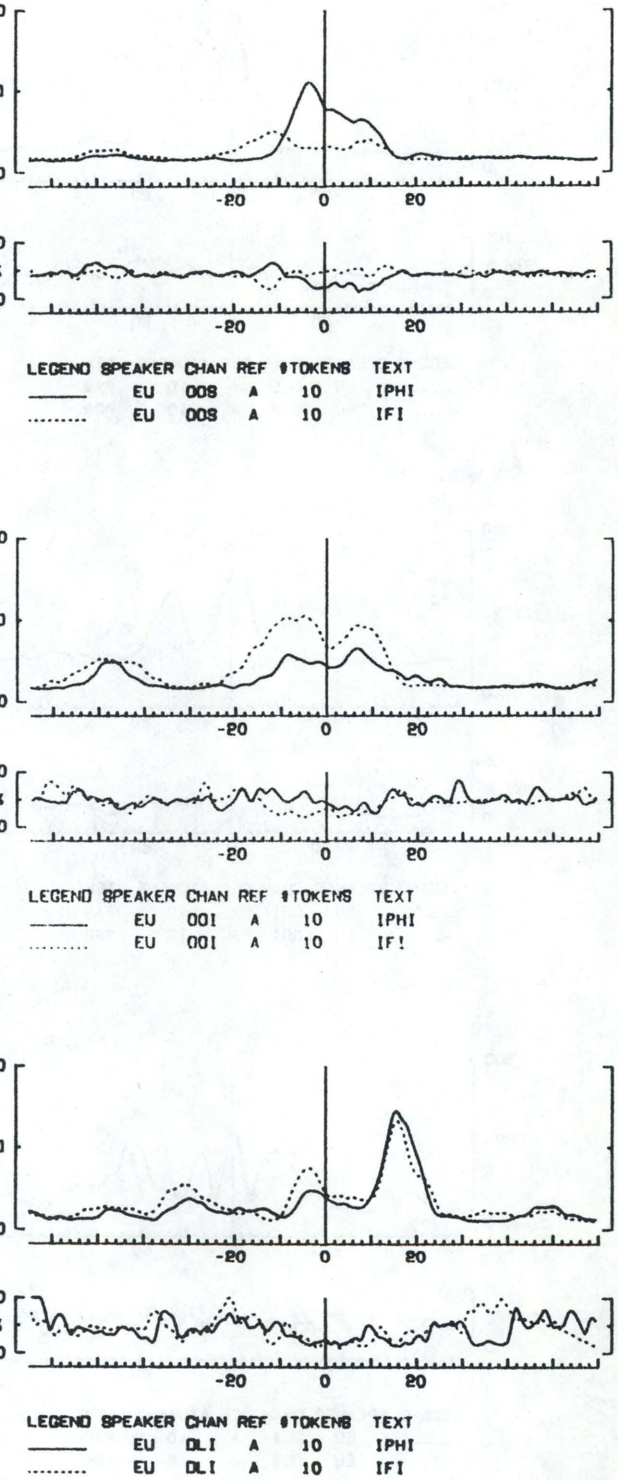

Figure 12

[iɸi] ——— , [ifi] ·····

(see further legend to Figure 1)

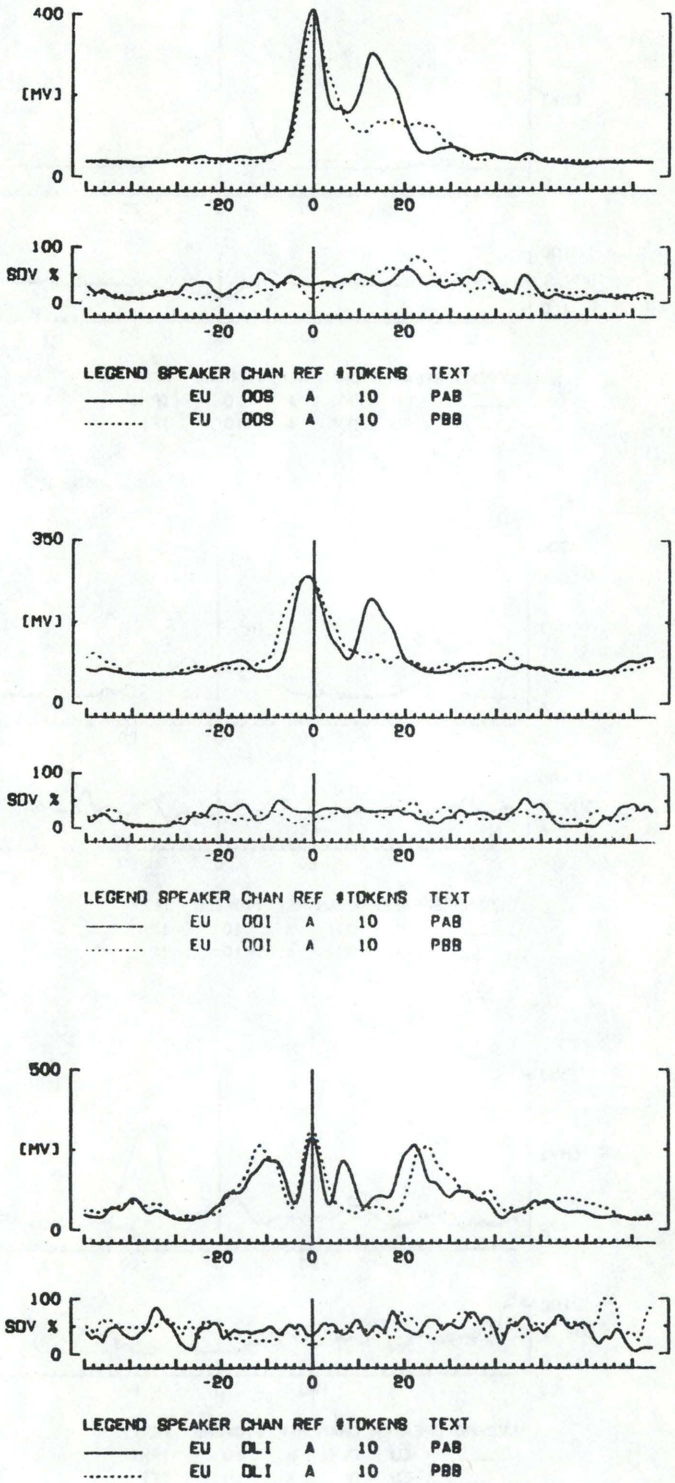

Figure 13

[keipəbəl] ——— , [keipb̩bəl] ·····

(see further legend to Figure 1)

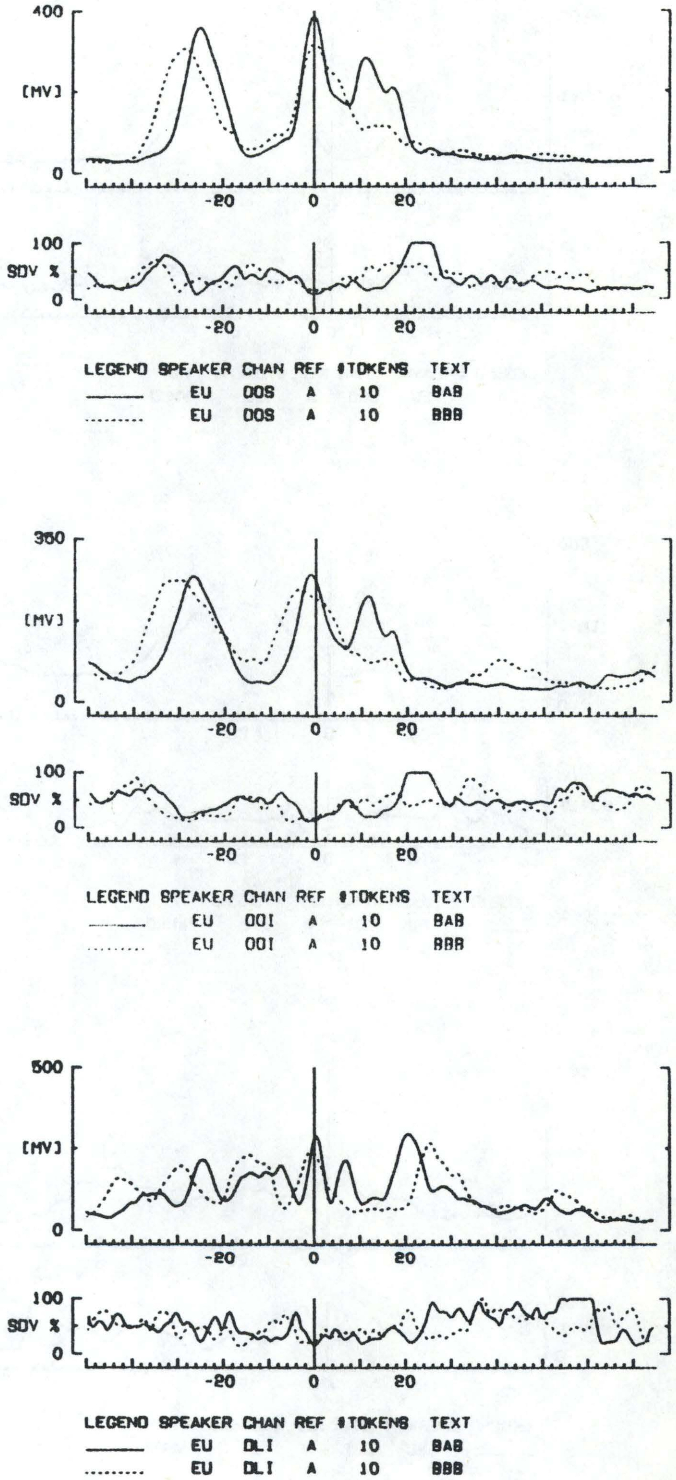

Figure 14

[prɑbəbəl] ——— , [prɑbb̩l] · · · · ·

(see further legend to Figure 1)

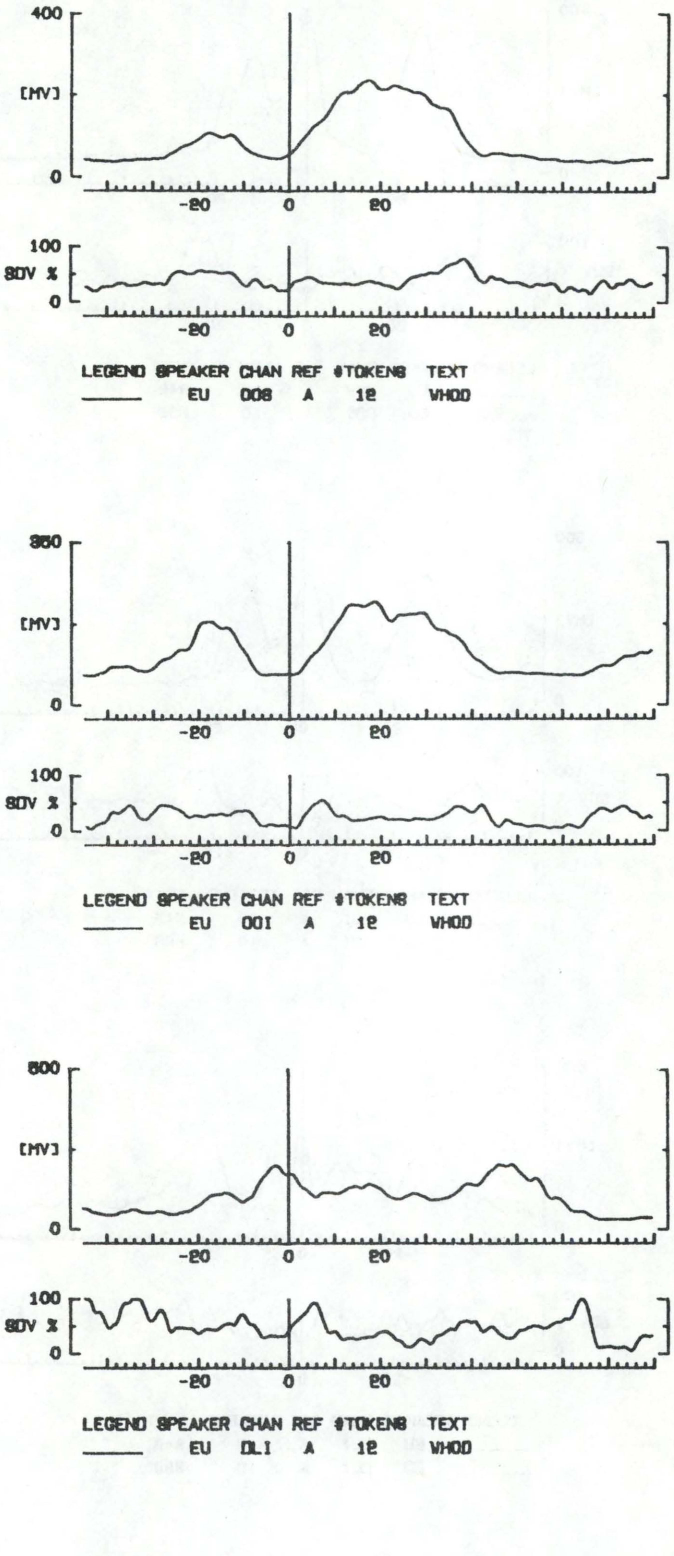

Figure 15

[hu:d]

line-up point boundary between [s] *and* [ei] *in the frame (see further legend to Figure 1)*

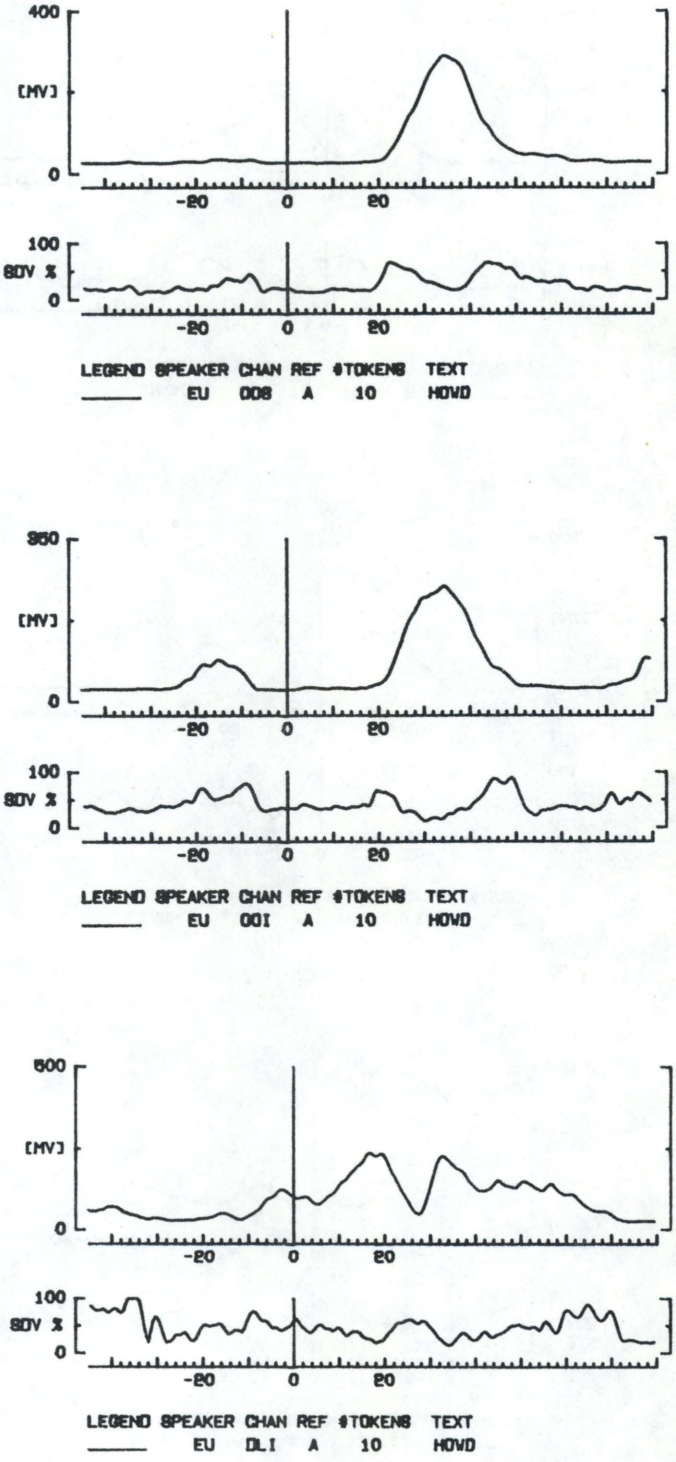

Figure 16

[haud]

line-up point as in Figure 15 (see further legend to Figure 1)

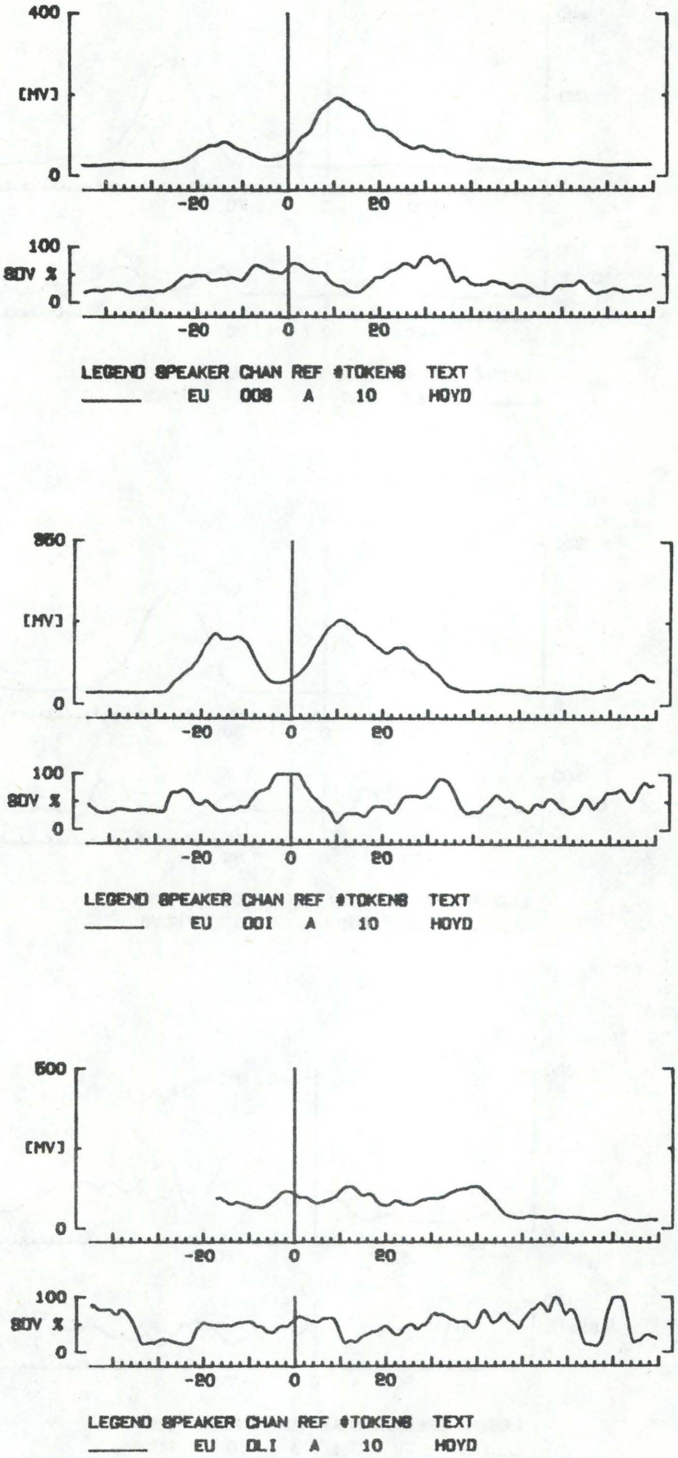

Figure 17

[hɔid]

line-up point as in Figure 15 (see further legend to Figure 1)