TONGUE POSITION IN ROUNDED AND UNROUNDED FRONT VOWEL PAIRS*

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Traditional articulatory descriptions of front rounded and unrounded vowel pairs have assumed that tongue height is the same for the members of the pairs /i-y/, /e-ø/, and /ε-œ/. The electromyographic, articulatory synthetic, and acoustic investigations carried out in this study indicate that, in Dutch, the rounded member of the pairs /i-y/ and /e-ø/ was centralized. In the /ε-œ/ pair, however, the rounded vowel bears a different relationship to its unrounded counterpart.

INTRODUCTION

General phonetic descriptions of the articulation of vowels portray pairs of rounded and unrounded vowels as having identical tongue heights (Fig. 1); idealized reference-grid schemes, such as Daniel Jones' Cardinal Vowel System (1940), define the vowel pairs [i-y], [e-ø], and [ε-œ] as having the same degree of tongue height and tongue advancement, and as differing in lip rounding.

In those classification schemes employing a category of tongue tension, the members of each pair are said to share this feature as well. This sort of generalized prescription, not specific to any language, has been rendered traditional through its repetition with little or no modification in the writings of many phoneticians including Abercrombie

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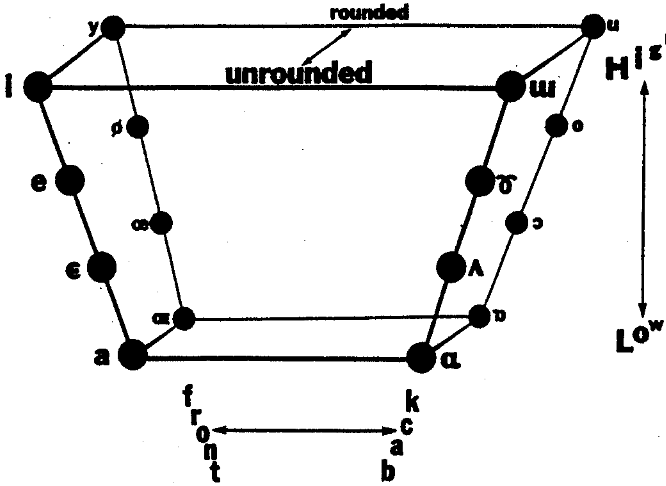

Fig. 1. Relative tongue positions for selected cardinal vowels.

(1967), O'Connor (1973), Smalley (1964), and Heffner (1950), among others. Delattre (1951), while noting that acoustic differences exist between rounded and unrounded front vowels in French, assigns the differences wholly to the frequency of the second formant and assumes that they are caused by differences in lip position and not tongue position. Viëtor (1921) provides a slightly different picture with regard to tongue advancement, with the rounded vowels being articulated further back in the mouth than their unrounded counterparts, but here too tongue height for the relevant vowel pairs is equated.

Although the descriptions mentioned above originated in an attempt to provide a reference grid for vowels that were not intended to be language-specific, they are often applied literally to the description of languages having both rounded and unrounded front vowels. For example, assumed equivalence of tongue height (as in the Cardinal Vowels) is implicit in the instructions often given to English speakers learning a language such as French: "say [i] and round your lips to produce the vowel of *tu*," although this may not reflect the actual production of a native speaker of French.

Dutch provides an example of a language which possesses front rounded and front unrounded vowels. The articulatory relationship between the two types of vowels received some attention a long time ago. In a 1928 study employing x-ray stills and palatography, Zwaardemaker and Eijkman described both /i/ and /y/ as closed vowels, and both /e/ and /ø/ as half-closed, although they reported a more advanced tongue position for the unrounded members of each pair. For the /ɛ-œ/ pair, a difference in overall mouth opening and presumably tongue height was reported between /ɛ/-half-open, and /œ/-

closed.[1] The authors also reported a difference in tongue tension and tongue advancement, with /ɛ/ being tense and front and /œ/ being lax and mid. For the members of each of the two vowel pairs which contrast primarily on the basis of lip rounding, the researchers found very similar averages and ranges for measurements of jaw opening.

Blanquaert's (1969) palatographic studies in the 1920's led him to conclude that although there may be some differences in tongue height and advancement between /i/ and /y/ and between /e/ and /ø/, "the main difference . . . must be sought in the position of the lips." He also noted that /ɛ/ and /œ/ are not related to each other in the same way as the members of the two other vowel pairs.

Wood (1975), looking at several languages not including Dutch, reported that vowels described as [y] are generally articulated with a lower mandible position than vowels described as [i], but with equivalent tongue advancement.

Finally, in a formant analysis of Dutch vowels, Pols, Tromp, and Plomp (1973) found that the second- and third-formant frequencies are lower for the rounded front vowels than for their unrounded counterparts, as predicted by the acoustic theory of vowels (Stevens and House, 1955; Fant, 1960; Lindblom and Sundberg, 1971), if the members of each pair differ only in lip position. First-formant frequencies, however, are not always lower for the rounded member of each pair, as the acoustic theory would predict. These data are summarized in Table 1. We will discuss the articulatory implications of these acoustic measurements in connection with our own data below.

METHOD

In the present study, acoustic and electromyographic (EMG) analyses of vowels were performed on the speech of one native speaker of Dutch. The test utterances contained twelve Dutch vowels embedded in [əpVp] nonsense words, randomized in lists and repeated 24 to 30 times each. Six of the twelve vowels constituted the three front rounded-unrounded vowel pairs which were the object of this investigation.[2] Examples of the test utterances are [əpip], [əpyp], [əpap], and [əpup]. Hooked-wire electrodes were inserted into the genioglossus (anterior fibers), mylohyoid, and anterior belly of the digastric muscles using standard procedures which are described elsewhere (Hirose, 1971;

[1] *Zwaardemaker and Eijkman (1928) consider /œ/ a "closed" vowel because, in their data, it has the same degree of jaw opening as /i/ and /y/. Traditionally, however, Dutch /œ/ is called "half-closed." Its sound quality is more closed than that of Cardinal Vowel [œ], which is "half-open." In fact, Dutch /œ/ and /ø/ contrast primarily in length, the former being phonetically short. This contrast, stable in both Northern and Southern varieties of Standard Dutch, is exemplified in the following minimal pairs:* keus *[ø:]-*kus *[œ] ('choice,' 'kiss');* reuk *[ø:]-*ruk *[œ] ('smell,' 'pull');* reus *[ø:]-*Rus *[œ] ('giant,' 'Russian');* leus *[ø:]-*lus *[œ] ('slogan,' 'loop').*

[2] *The six vowels studied were: /i/ (*dier *'animal,'* hier *'here'); /y/ (*duur *'expensive',* huur *'rent'); /e/ (*geel *'yellow,'* leek *'layman'); /ø/ (*geul *'channel.'* leuk *'nice'); /ɛ/ (*rek *'stretch,'* vel *'skin'); and /œ/ (*ruk *'pull,'* vul *'fill').*

TABLE 1

Average formant frequencies for Dutch rounded-unrounded vowel pairs

		/i/	/y/	/e/	/ø/	/ε/	/œ/
	F_1	242	277	341	375	538	382
(a)	F_2	2006	1691	1956	1530	1508	1400
	F_3	2902	2111	2669	2229	2377	2238
	F_1	294	305	407	443	583	438
(b)	F_2	2208	1730	2017	1497	1725	1498
	F_3	2766	2208	2553	2260	2471	2354

a. Averaged formant frequencies for one native Dutch speaker. The number of utterances averaged for each vowel pair ranged from 9 to 12.

b. Averaged formant frequencies for 50 native Dutch speakers. From Pols, Tromp, and Plomp, 1973.

Raphael and Bell-Berti, 1975). EMG potentials were also recorded from the orbicularis oris muscle, which is active in rounding the lips. These data are not discussed below, since, as we might expect, this muscle showed considerably more activity for the rounded than for the unrounded members of the pairs [i-y], [e:-ø:], and [ε-œ], and this activity is quite similar for the rounded vowels [y,ø:,œ]. The EMG potentials were then rectified, integrated and computer-averaged. The EMG signals and functions derived from them were aligned with reference to the onset of the voicing of the stressed vowel of each utterance.

The acoustic analyses were performed using a digital-waveform and spectral-analysis system. Formant frequencies for nine to twelve repetitions of each stressed vowel were determined at a point approximately equidistant from the surrounding consonant closures. That is, the measurements were made for that portion of each vowel that most closely approximated a steady state.

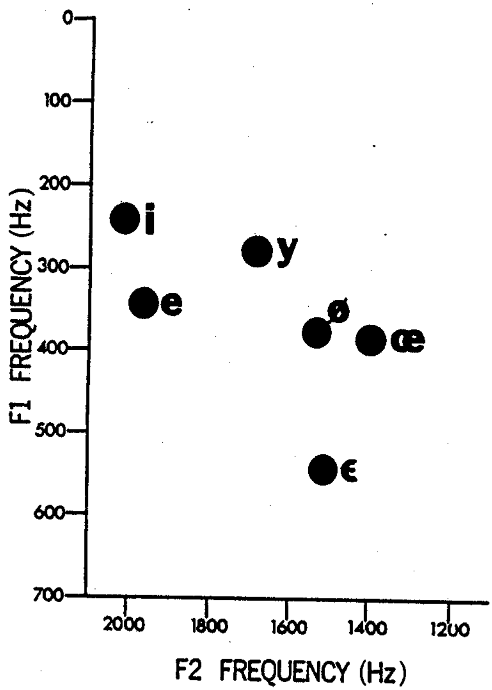

Fig. 2. Frequency of the first formant versus frequency of the second formant for rounded and unrounded front vowels for a speaker of Dutch.

RESULTS

Acoustic analyses

We will confine our discussion here to the front pairs of rounded and unrounded vowels which are found in Dutch: /i-y/, /e-ø/, and /ɛ-œ/.

The formant-frequency values resulting from the analysis of our subject's speech generally agree with the data of Pols, Tromp, and Plomp (1973) as to the relationships between these vowels, as can be seen in Table 1, where values are given for the first three formants.[3] F_1 and F_2 data for our subject are also presented in Fig. 2. All of these data

[3] *The differences between our data and those of Pols, Tromp, and Plomp (1973) may have two different causes. First, our data are measurements of one speaker's productions of the target vowels in a /əpVp/ frame, while the Pols, Tromp, and Plomp data are averages of 50 speakers' productions of the target vowels in a /hVt/ frame. Second, our speakers's dialect is Southern Dutch, while the speakers in the Pols, Tromp, and Plomp study spoke Northern Dutch.*

agree with the predictions, presented above, of the effect of rounding on F_2 and F_3, since lip-rounding effectively lengthens the vocal tract, lowering the second- and third-formant frequencies. On the other hand, these data do not always agree with the prediction that the effect of rounding on first-formant frequency is to lower it.

The articulatory implications of these data are that the vocal-tract differences between members of pairs cannot be due to lip rounding alone. We assume, in the following discussion, that relative tongue position can be inferred from an F_1–F_2 frequency plot for vowels having the same lip position. Since lip rounding is expected to lower both F_1 and F_2, and F_1 is higher for the rounded members of the [i-y] and [e:-ø:] pairs, the tongue must be lower for the rounded members of these pairs. However, we cannot describe these differences in tongue position on the basis of the acoustic data alone.

The higher first-formant values for the rounded members of the [i-y] and [e:-ø:] pairs indicate centralization on the vertical axis. In the case of the [ε-œ] pair, the situation is less clear. The lower first-formant value for [œ] suggests that this vowel is no closer to the tongue height of a mid-central vowel than is the unrounded [ε], but rather, that the tongue height is closer to that of the half-closed vowels [e:] and [ø:]. In general, however, centralization of tongue position, as inferred from formant-frequency measurements, seems to mark the front rounded vowels and to distinguish them from the front unrounded vowels.

EMG analyses

Before presenting the EMG data it will be necessary to make explicit certain assumptions underlying their interpretation. The first assumption is that if, in a constant framework, the EMG potentials recorded from the tongue muscles are different, that tongue position and, hence, vowel quality, will be different.[4]

The second assumption (and those that follow it) concerns muscle function: the genioglossus is the only muscle which contributes significantly to tongue advancement (fronting) for the front vowels being considered here. Further, it is assumed that virtually all tongue fronting gestures for low vowels can be accounted for by relatively moderate amounts of genioglossus activity. We are thus led to a third assumption, which is that genioglossus activity which exceeds levels needed for near-maximum tongue fronting for low vowels contributes primarily to the raising and bunching of the tongue as well as to further tongue advancement. The second and third assumptions taken together suggest that with the tongue body low in the mouth, relatively little muscular contraction is needed to push the tongue as far forward as it will go. More contraction, assuming the tongue tip to be bent down and resting behind the lower teeth, will cause the center of the tongue to rise (bunch) toward the post-alveolar area of the palate and to be increasingly more advanced as it rises to its highest and most fronted position. We suggest,

4 *This assumption concerns the nature of EMG activity itself and its relationship to articulator movement. Although the relationship between EMG activity and muscle tension is not linear, we assume that within a constant framework the relationship is monotonic, and therefore, that relatively stronger EMG potentials result in relatively greater muscle tension and, therefore, greater articulator displacement.*

then, that the direction of the rise of the high point of the tongue attributable to genioglossus contraction is oblique, along an anterior-superior line, and that the strength of genioglossus contraction will be roughly proportional to tongue height, for front vowels (Smith, 1970; Raphael and Bell-Berti, 1975; Kakita, 1976; and Perkell, 1974).

Our fourth assumption is that mylohyoid activity raises the tongue body through the application of a nearly vertical force. The effect of mylohyoid contraction on tongue height varies, depending on the activity of the genioglossus and the anterior belly of the digastric.

Previous research throws some light on the possible interaction of the mylohyoid with the genioglossus. First, for vowels, both muscles display maximum contraction for [i] (Harris, 1971; Faaborg-Anderson and Vennard, 1964). Second, genioglossus activity decreases for the front vowel series as the tongue is retracted and lowered (Smith, 1970; Raphael and Bell-Berti, 1975). Given these findings, we would expect that, all other things being equal, mylohyoid contraction becomes proportionately more important for tongue raising as genioglossus activity decreases. Thus, for example, if two front vowels are articulated with identical tongue heights but with different degrees of tongue advancement, then mylohyoid contraction should contribute proportionately more to the raising of the tongue for the less advanced vowel than for the more advanced vowel. This follows simply because the genioglossus simultaneously raises and fronts the tongue: thus, the less fronting it accomplishes, the less raising as well, and so the mylohyoid contraction, with its vertical force, becomes relatively more important in maintaining tongue height.

Our final assumption is that the effect of activity of the anterior belly of the digastric is to lower the jaw and, in lowering the jaw, it counteracts the activity of the mylohyoid, and, to a lesser extent, the activity of the genioglossus. Jaw lowering increases, for the vowels considered here, only as articulation occurs progressively further back in the mouth, and as we have seen, tongue height for front vowels depends proportionally more on mylohyoid than on genioglossus activity as the degree of fronting decreases.

At a first approximation, then, tongue height for front vowels is determined by the combined activity of the genioglossus and mylohyoid, less the activity of the anterior belly of the digastric.[5] Of course, this is not a formula for tongue height of the sort that might be proposed if the anterior belly of the digastric were a true antagonist to either the mylohyoid or the genioglossus, or if the relationship between the various muscular forces and EMG measures were quantitatively known.

The EMG data

Let us turn now to the electromyographic data to see if they confirm the relative front vowel positions inferred from the acoustic data, and what additional insights they provide about tongue position. The EMG data are displayed in Fig. 3. Each plot in the figure shows a schematized representation of the time-course of EMG activity for each vowel as

[5] *Of course, specifying tongue height completely requires additional information, including, but not limited to, the activity of the internal pterygoid, the muscle that raises the jaw in speech.*

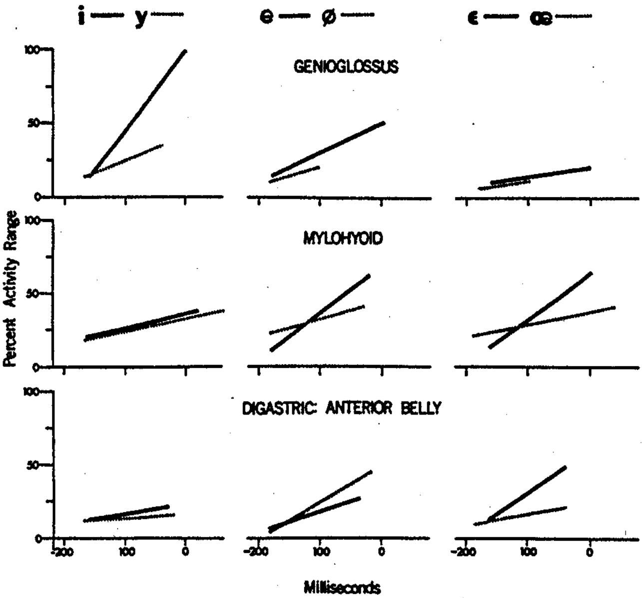

Fig. 3. Normalized EMG data, schematized as percent of maximum range of activity, from onset of activity to peak of activity, for each muscle.

a percent of the overall range of each muscle's activity across vowels. The range of activity was determined by subtracting the baseline averaged EMG activity for a muscle from the maximum averaged EMG activity for that muscle for any utterance (including the vowels not discussed in this paper). In Fig. 3, the minimum points were derived by dividing the averaged EMG activity (after subtracting baseline activity) at the beginning of the vowel gesture by the range of activity. Similarly, the maximum points were derived by dividing the maximum averaged EMG activity for the vowel (after subtracting baseline activity) by the range of activity. Activity is plotted as a line from the point of onset to the point of peak vowel activity.

Tongue movements toward a vowel may begin before voice onset for the vowel and, in addition, there is a time delay between EMG activity and its movement consequences. Thus EMG activity commences some time before the vowel is heard. The moment of initiation of voicing for a given vowel is marked by the zero point at the right of the abscissa in each graph. It will be recalled that this is the point of alignment of the EMG signals for all the tokens of a given utterance type. We shall consider each pair of vowels in turn.

[i] v. [y]: The moderate degree of genioglossus activity for [y] serves to advance the high point of the tongue and to raise it, but not to the extent that it is raised and advanced by the comparatively more vigorous contraction for [i]. For this vowel pair the activity

of the other muscles is either at a relatively low level (i.e., anterior belly of the digastric), or the activity is essentially the same from one vowel to the other (i.e., mylohyoid). Thus, the tongue is apparently somewhat higher and more advanced for the unrounded member of this vowel pair.

[e:] v. [ø:]: The differences in genioglossus, mylohyoid, and anterior belly of the digastric activity for this vowel pair indicate that the tongue is both higher and more advanced for [e:] than for [ø:]. Both the genioglossus and the mylohyoid are more active for [e:], producing both greater tongue height and advancement, while the anterior belly of the digastric is more active for [ø:], implying more jaw lowering for the rounded vowel. Taken together, these EMG data indicate that the tongue is less advanced and lower for the rounded vowel of the pair.

[ε] v. [œ]: Genioglossus activity is at a relatively low level for both vowels of this pair. Only [ø:], among the other vowels, displays the same low level of genioglossus activity found for both members of this pair. However, the genioglossus activity, persisting for substantially longer for [ε] than for [œ], seems to indicate slightly more tongue advancement for the unrounded vowel than for its rounded counterpart. Both the mylohyoid and the anterior belly of the digastric are considerably more active for [ε] than for [œ], indicating that both tongue raising and jaw lowering are greater for the unrounded vowel of this pair: it is impossible, however, to determine which is more effective. Obviously, though, we cannot describe tongue height differences from the EMG data alone.

The acoustic analysis suggested that [ε] and [œ] differ from the other vowel pairs in that the rounded vowel appears to have a higher tongue position than the unrounded vowel. This height difference may be attributed to the interaction of the activity of the mylohyoid and the anterior belly of the digastric muscles. Although there is more mylohyoid activity for [ε] than for [œ], this activity is counteracted by the contraction of the anterior belly of the digastric for the [ε]. This finding closely parallels Zwaardemaker and Eijkman's 1928 description of [ε] as half-open and of [œ] as closed, although we would prefer half-closed as a descriptor for [œ] on the basis of the EMG and acoustic data. On the other hand, tongue height may be essentially the same for these vowels, with lip rounding entirely accounting for the lower first-formant frequency of the rounded member of the pair.

Analysis by articulatory synthesis

The conclusions drawn from the acoustic and EMG data were tested using an articulatory synthesizer (Mermelstein, 1973; Cooper, Mermelstein, and Nye, 1977). An exemplar of each of the unrounded vowels was produced by adjusting the positions of the supraglottal articulators until a satisfactory vowel was heard as the output of the synthesizer. The first three formant frequencies were then recorded. The behavior of the model with respect to the first three formants was then investigated as a function of: lip rounding alone, and lip rounding together with jaw and tongue position adjustments. Since the changes in the frequencies of both the second and third formants were always in the same direction, we have plotted only the second-formant values in Fig. 4.

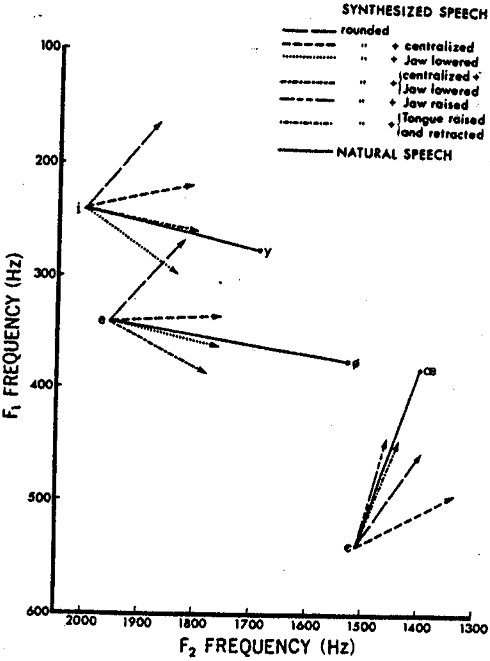

Fig. 4. Frequency of the first formant versus frequency of the second formant for natural and synthetic rounded and unrounded front vowel pairs. Solid lines connect natural-speech values for each pair. The arrows indicate the direction of formant-frequency change resulting from articulatory adjustments, as described in the text.

As expected, lip rounding alone always lowered all three formant frequencies. Increasing the first-formant frequency for the rounded members of the [i-y] and [e:-ø:] pairs could be produced with either a lowered jaw position or a lowered jaw position together with centralization of the tongue body. For the [ɛ-œ] pair, changes in the direction of those observed in our native speaker could be produced with lip rounding and a combination of jaw raising and tongue raising and retracting. Thus, our hypothesis about articulatory movements, based on the acoustic and EMG data, appears to be confirmed.

Discussion

Both the electromyographic (especially genioglossus) and acoustic data of this study indicate that the Dutch front unrounded vowels /i/ and /e/ are articulated with the high point of the tongue in a higher and more advanced position than their rounded counterparts /y/ and /ø/. (This conclusion was supported by the results of the articulatory synthesis experiment reported above.) To put it another way, we might say that the rounded vowels are marked by centralization of the high point of the tongue in relation to their unrounded counterparts and not only differences in tongue height, as suggested by Wood (1975). Thus we can see from the EMG data that the lowered second- and third-formant frequencies result in part from differences in tongue position, and not only from the increased cavity length attributable to lip rounding. It is of note that these differences in tongue position are caused in different ways: in the /i-y/ case the difference is primarily in genioglossus activity, while in the /e-ø/ case the different positions appear to be caused by differences in activity of the mylohyoid and anterior belly of the digastric as well as genioglossus activity. We might add that this point cannot be derived from the analysis of the acoustic signal alone.

Thus, our data, in concert with those of Pols, Tromp, and Plomp (1973) and Wood (1975), do not support the orthogonality between tongue and lip position proposed by some phoneticians in their descriptions of articulatory behavior. Rather, we are led to speculate that the lack of orthogonality may be general among natural languages. To this end, more languages and speakers need to be studied, particularly phoneticians trained in the Cardinal Vowel tradition. If these speakers display orthogonality in their productions of the Cardinal Vowels, it will be possible to eliminate physiological restrictions as the basis for the observed differences in tongue position between the members of the rounded and unrounded front vowel pairs.

Our data further indicate that there is a qualitative difference between the two vowel pairs /i-y/ and /e-ø/, and the third pair /ε-œ/. It seems clear that /ε/ and /œ/ do not constitute a rounded-unrounded vowel pair in the same sense that /i-y/ and /e-ø/ do. In this we find ourselves in substantial agreement with other investigators (Zwaardemaker and Eijkman, 1928; Blanquaert, 1969; Pols, Tromp, and Plomp, 1973).

We might also note, in passing, that the dimension of vowel height is implemented differently from the unrounded to the rounded series of vowels. For the unrounded /i-e-ε/ series we find (1) decreasing genioglossus activity, (2) increasing anterior belly of the digastric activity, and (3) an increase in mylohyoid activity from /i/ to /e/, but not from /e/ to /ε/; for the rounded /y-ø-œ/ series we find (1) a more subtle gradation in genioglossus activity, (2) an increase in anterior belly of the digastric activity from /y/ to /ø/, but a decrease in activity from /ø/ to /œ/, and (3) very little variation in mylohyoid activity.

In addition, apart from the question of the relative tongue position in the pairs considered here, we might note that the apparent difference in tongue height between /ε/ and /œ/ confounds traditional descriptions of their positions: the distance between /e/ and /ε/ is much greater than the distance between /ø/ and /œ/, at least in the dialect of our subject.

Further investigation is indicated to determine if lowering and centralization of tongue position is a general property of the so-called front rounded vowels in relation to their unrounded counterparts in languages other than Dutch (and in speakers other than our subject). One might also wish to discover whether some other language, such as Danish or Turkish, possesses a third pair of front vowels the members of which are related to each other as /i/ and /e/ are related to /y/ and /ø/, respectively, in Dutch.

As a final note, we find it interesting that lowering and centralization characterize rounded (front) vowels in their opposition to the corresponding unrounded ones, and, at the same time, they characterize "lax" vowels in their opposition to their "tense" counterparts (Ladefoged, 1975).

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