An EMG Study of the German Vowel System

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Abstract

To investigate whether the two vowel classes of German are systematically produced with different muscular tension and could thus be classified as long "tense" vs. short "lax" vowels, electromyographic data was recorded from five German subjects. The extrinsic tongue muscles Genioglossus anterior and posterior, Styloglossus and Hyoglossus were recorded by means of hooked-wire electrodes. These muscles are said to be mostly responsible for the gross changes of tongue position in the mouth necessary for vowel production [2]. The speech material consisted of C-V-C sequences containing all German vowels in either bilabial or velar context. For several vowels the expected pattern of stronger activation for the long counterparts was found: this was most obviously the case for /i:,e:,y:/ with GGP as most active muscle, and /u:/ with SG as most active muscle.

However, there were important exceptions, in particular for low back vowels involving strong HG activation, i.e. short /a,O/ showed more activity than long /a:,o:/. We conclude that a linguistic opposition such as tense vs. lax cannot be associated in a simple one-to-one manner with muscular activity, as it seems to depend on the required movement and the time available for it.

1 Introduction

This paper presents an electromyographic study of the German vowel system. The bulk of the German vowel system can, similarly to English, be divided into pairs contrasting in duration and quality, often referred to as tense vs. lax. One of the proposed underlying articulatory features differentiating these vowel pairs is thought to be the muscular tension of the tongue muscles involved in the production of these vowels. A higher muscular tension is assumed to result in further deviation from the neutral position and greater duration of the supposedly long tense vowels compared to their short lax counterparts [6].

With respect to vowel inventory German is more appropriate for an EMG study than the more frequently studied English. German /i:/ and /u:/, for example, are more peripheral than the English counterparts, and German vowels maintain a constant vowel quality [6]. The tense-lax opposition is not complicated by the diphthongization that is very characteristic of many English vowels as described by several authors [1,7,8] examining English vowels by means of EMG. As the status of the two vowel classes with respect to muscular tension is not clear in Geman, we will refer to them as long vs. short in the following paper.

2 Data

In this study electromyographic data was recorded from the tongue muscles Genioglossus anterior (GGA), posterior[1] (GGP), Styloglossus (SG) and Hyoglossus (HG) by means of hooked-wire electrodes. In addition, Anterior Belly of the Digastricus, Orbicularis Oris and Mylohyoideus were recorded using. This data as well as a detailed description of insertion techniques, signal amplification and further processing can be found in [10]. Subjects were five native speakers of German (four male, one female). The speech material consisted of symmetrical nonsense words in the form of CVC@ embedded in the carrier phrase "habe … besucht" (visited …). Both consonants were either bilabial /p/ or velar /k/. In addition, the syllable preceding and following the target word was neutral with respect to tongue position (b@). The consonant contexts were intended to contrast cases with (velar) and without (labial) involvement of tongue dorsum in both vowel and consonant. The vowels to be tested in the C-V-C sequences were the pairs /i:,I; e:,E; a:,a; o:,O; u:,U/[2] for all subjects and the front rounded vowels /y:,Y; oe:,OE/ and /E:/ in the bilabial context for the last two subjects only. The number of repetitions ranged from 7 to 20 per subject.

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[1] The functional division of Genioglossus into anterior and posterior was adopted from Maeda & Honda [7].
[2] For the purpose of this paper a modified SAMPA notation is used.

3 Processing of data

To convert the high-frequency interference pattern of the EMG-signal into a low-frequency signal reflecting the bandwidth of speech movements [4, 5], the RMS-amplitude was calculated over a sliding window. The window of 40ms length was shifted in steps of 2.5ms for the duration of the vowel. Vowels were segmented from voicing onset to offset. We chose the vowel mid-point as time point for analysis taking into account an assumed delay of 70ms between muscle activity and acoustic output. Afterwards, the 1st derivative of the raw signal (RMSD) was calculated, functioning as an additional high-pass filter [4].

4 Results

Some of the recordings could not be included in the analysis as some muscles showed no clear activation pattern at all or quite evenly distributed activity over all vowels. Altogether there were recordings of GGA from two subjects, of GGP from four subjects, of SG from five subjects and of HG from two subjects suitable for further analysis. For all muscles multifactorial ANOVAs were performed for each subject ($\alpha = 0.05$). The factors “vowel” (i,e,a,o,u), “duration” (long, short) and “context” (p,k) were used.

For GGA and HG data from only two subjects was available, therefore no standard deviation is shown in these graphs. The values presented in this section correspond to the normalized and averaged data from all subjects. For each muscle, a graph shows the activity by duration (long, short) and context (/p/, /k/).

4.1 GGA

As can be seen in figure 1 GGA is generally more active for the front vowel group, especially for the high front vowels /i:,e:/ in bilabial context. It is least active for short low and back vowels. All long vowels /i:,e:,a:,o:,u:/ exhibit greater activity in both contexts than their short counterparts /I,E,a,O,U/ which is significant for /i:,e:/ vs. /I,E/. Interestingly, activity for the short vowel /I/ is not only less than for its long counterpart /i:/, but particularly in p-context also less than for /e:/ the next lower long vowel in the vowel chart [6]. Comparing the consonant context, there is more muscular tension in the /p/-context for long /i:,e:,u:/ and short /O,U/, whereas for short /I,E,a/ and long /a:,o:/ in velar context which is more pronounced for the front group. The higher values for short vowels in the velar context are probably due to GGA activity during the release of the constriction and the forward movement of the tongue after the initial plosive.

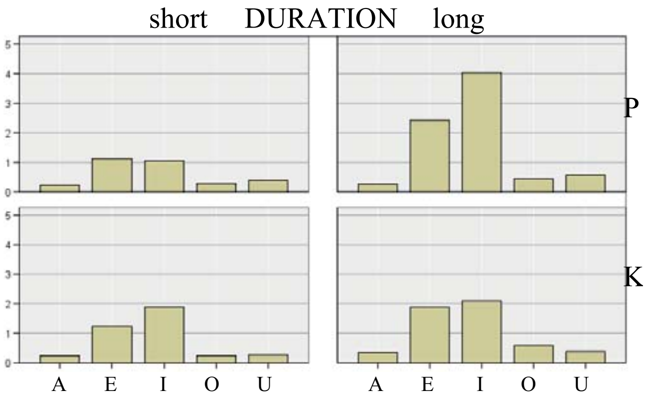

Figure 1: *Activity of GGA normalized to average activity level. Data from two subjects.*

4.2 GGP

Figure 2 illustrates the results of GGP. Overall it is more active for the high vowels. Most activity is found in the front vowel group, whereas it is least for the low vowels /a:,a,O/. Except for /a/ in velar context GGP shows more tension for all long vowels /i:,e:,a:,o:,u:/ compared to their short counterparts /I,E,a,O,U/. The clearest differences are between the high vowels /i:,e:,u:/ and /I,E,U/. For one subject out of two recordings there was significantly higher activity for the long front rounded vowels /y:,oe:/ compared to /Y,OE/. As with GGA, GGP is not only less active for the front short vowel /I/ than for its long partner, but also for /e:/, the next lower vowel in the vowel chart. When GGP is very active as in /i:,I,e:,E,o:,u:,U/ the values are somewhat higher in bilabial context. Presumably tension is lower in velar context as activity decreases for the vowel between the two velar plosives.

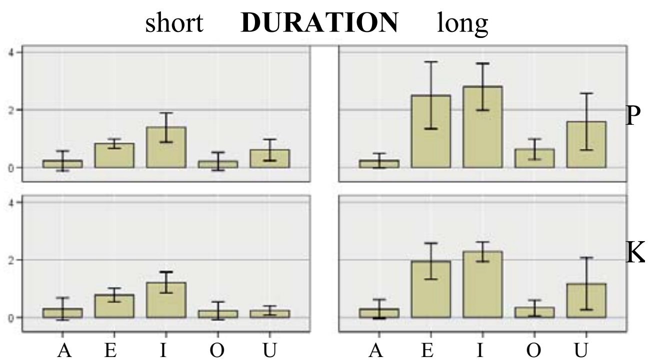

Figure 2: *Activity of GGP normalized to average activity level. Data from four subjects.*

4.3 SG

SG is clearly more active for back vowels, in particular for high back vowels as illustrated in figure 3. Within both the front and back vowel group there is more tension for the long vowels /i:,y:,e:,oe:,o:,u:/ than for their short counterparts /I,Y,E,OE,O,U/ which is more pronounced in the back vowel group. The back vowels /o:,u:,U/ and front /e:/ show more activity in bilabial context, whereas /i:,I,E,a,a:,O/ exhibit greater tension in velar context. In a velar sequence SG is highly active for /k/, so that its activity has to decrease for the vowel. This allows tongue lowering by HG for example. It seems likely that the higher tension in /i:,I,E,a,a:,O/ results from overlap of activity for the neighbouring /k/s. The greater tension for /o:,u:,U/ in bilabial context compared to velar context calls for a different explanation. In a p/o:,u:,U/p sequence the tongue is located more front and down before the target vowel and has to be moved further back and up by SG than k/o:,u:,U/k, yielding higher activity.

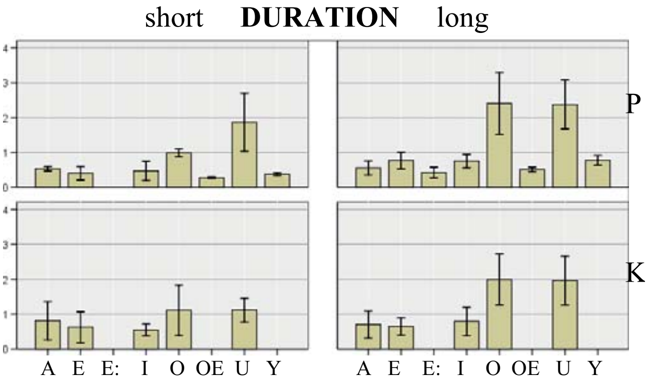

Figure 3: *Activity of SG normalized to average activity level. Data from four subjects. The vowels /oe:, OE; y:,Y; E:/ were not recorded in velar context.*

4.4 HG

Finally, the activity pattern of HG is illustrated in figure 4. This muscle is most active for the low and back vowels /a:,a,o:,O,u:,U/, again confirming the English data [1]. There are no consistent tense-lax differences in the front vowel group. However, among the low and back vowels there is more activity for the short vowels /a,O,U/ than for long /a:,o:,u:/ in both contexts. The higher tension for short vowels is presumably due to less time available to reach the target position for these vowels compared to their long counterparts. Generally there is somewhat more activity in velar context, especially for the low and back vowels /a:,a,O,U/. The context offers another explanation for the increased tension of HG for short low and back vowels. As the tongue is in its highest vertical position before and after the vowel, a greater movement is needed to reach the target of low back vowels such as /a:a,O,U/, that is stronger activation of HG is needed. It would be conceivable that conditioned by the velar consonant there is even less time for the vowel production which evokes stronger muscular activity. This adds to the shorter time available for the production of a short vowel compared to a long one accounting for the particularly high muscular tension for the vowels /a,O/.

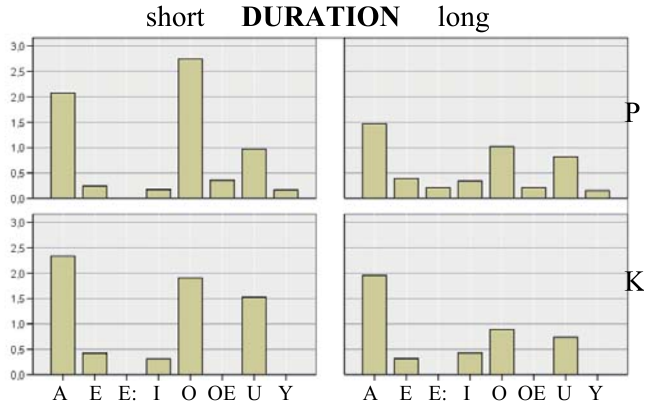

Figure 4: *Activity of HG normalized to average activity level. Data from two subjects. The vowels /oe:, OE; y:,Y; E:/ were not recorded in velar context.*

5 Discussion

Electromyographic data was recorded from the extrinsic tongue muscles GGA, GGP, SG and HG using hooked-wire electrodes. The aim was to find out whether the two vowel classes are produced with different muscular tension and the German vowels could be classified as long "tense" vs. short "lax" vowels.

As reported for English [1] and Swedish [3], GGA is generally more active for the front vowel group. In our data the higher muscular tension for the front vowels /i:,e:/ than for /I,E/ is significant in two subjects. In their English data Baer & Alfonso [1] found most activity for the front low vowel /ae/. Although we recorded /E:/ for two subjects, no reliable signal could be obtained. Therefore no statement can be made concerning its peak activity level. GGP is more active for the high vowels confirming the results for both English [1,8,9] and Swedish [3]. The clearest differences in tenseness are between the high vowels /i:,e:,u:/ and /I,E,U/. This again replicates the findings for English [1,8] and Swedish [3]. In our German data the differences between /i:,e:,u:/ compared to /I,E,U/ were significant in four, for /o:/ compared to /O/ in two and for /y:,oe:/ compared to /Y,OE/ in one subject out of the two recorded.

SG is clearly more active for back vowels, in particular for high back vowels. This has been previously reported for English [1,9]. However, unlike English [1,8] German seems to have more consistent differences between long and short vowels. Within both the front and back vowel group muscular tension of SG is significantly higher for the long vowels /i:,e:,o:,u:/ than for /I,E,O,U/ in four subjects and /y:,oe:/ compared to /Y,OE/ in two subjects. Finally, HG is most active for the low and back vowels, again confirming the English data [1]. No consistent tense-lax differences have been reported earlier which is also true for the front vowel group in German. Among the low and back vowels however, there is significantly greater muscular tension for the short vowel /O/ in both subjects involved and for /a, U/ in one subject.

Taking all subjects into account there is a tendency for greater tension in long vowels compared to short ones in bilabial context and also for short vowels in bilabial context compared to velar context, i.e. without conflicting consonantal context. As an exception to this, HG is most active for the short vowels.

In summary the expected pattern of stronger activation for the long counterparts was found for some vowels, especially for /i:,e:,y:/ with GGP as most active muscle, and /u:/ with SG as most active muscle. However, there were important exceptions, in particular for low back vowels involving strong HG activation, i.e. short /a,O/ showed more activity than long /a:,o:/. These cases also made it very clear that the level of vocalic muscular activity cannot be regarded independently of consonantal context. A C-V-C sequence such as /kOk/ requires a fast downward movement for the short low vowel between the neighbouring velars. To produce this movement it is necessary to apply a greater muscular force by HG for /O/ compared to /o:/ as the short vowel offers less time for its execution and the dorsal consonant /k/ prevents anticipation of the vowel during the consonant.

Consequently, a linguistic opposition such as tense vs. lax cannot be associated in a simple one-to-one manner with muscular activity, as it seems to depend on the required movement and the time available for it. Generally speaking, the greater the movement, the more activity is needed. Depending on the consonantal context, either the short or the long vowel might require the relatively greater movement and thus exhibit the relatively greater or lesser muscular tension. In cases when a muscle is most active for the neighbouring consonants as GGP is for k [9], the tension has to be reduced more for the vowel between the two maximums of activity. In order to release the initial consonant in the sequence /kIk/ and move the tongue towards /I/ the activity has to be reduced more in comparison to the sequence /pIp/. The same holds for SG in a /kUk/ vs. /pUp/ sequence.

Generally, the terms “tense” and “lax” cannot be associated with the underlying muscular tension in German, so that the long vowels are systematically tense and the short vowels lax.

We are currently continuing the analysis by considering whether the German data are compatible with the functional division into antagonistic pairs (GGA vs. SG, GGP vs. HG) as proposed by Maeda and Honda [7].

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