INTRINSIC VOWEL PITCH: A GRADIENT FEATURE OF VOWEL SYSTEMS ?

Paul Turner, Jo Verhoeven

City University London, Department of Language and Communication Science
Paul.turner.1@city.ac.uk, jo.verhoeven@city.ac.uk

ABSTRACT

This paper investigates the average fundamental frequency of eight peripheral vowels in Belgian Standard Dutch in order to examine whether a vowel gradient exists with respect to Intrinsic Vowel Pitch (IF0). The results show that IF0 exists in Belgian Standard Dutch and amounts to 3.26 semi-tones. It is found that the assumed gradience in the degree of openness/tongue height is only reflected to a certain extent in vowel F0: mid vowels have intermediate values between those of high and low vowels and there is no significant difference between the close-mid and open-mid vowels. This suggests that gradience in the degree of opening in vowel articulation does not correspond directly to a gradient change in F0, but that the mechanical coupling between articulation and the laryngeal system has a non-uniform effect on intrinsic vowel F0.

Keywords: Intrinsic vowel pitch, prosody, vowel systems.

1. INTRODUCTION

Intrinsic vowel pitch (IF0) refers to the phenomenon in which the mean F0 of high vowels is higher than the F0 of low vowels in vowel systems. This phenomenon has been attested for a wide variety of languages. For a comprehensive survey of IF0 research, the reader is referred to [1] who have analysed the findings of IF0 research to date. They have found that IF0 is a language universal and that it applies equally well to the front and the back dimension of vowel articulation. Thirdly, it was found that there are significant IF0 differences between male and female speakers. Fourthly, recent evidence suggests that there is a significant relationship between vowel inventory size and IF0 [2].

Finally, we should mention one additional aspect i.e. the question whether IF0 is a gradient feature of vowel systems. So far, most IF0 research has concentrated on the F0 difference between high and low vowels and there has been far less attention to F0 in the vowels at intermediate degrees of opening. If it were found that IF0 is a gradient feature, it would provide support for claims that the source of IF0 is to be found in muscular adjustments related to tongue height. [1] seem to imply that IF0 is a gradient feature of vowel systems, which is confirmed by the results of at least one study, i.e. Reinholt-Peterson's investigation of IF0 in Danish [4]. His results suggest that average F0 decreases progressively with increasing degrees of vowel openness. In Connell's investigation of African languages ([3]), however, no strong evidence was found either for or against the existence of a vowel gradient with respect to IF0. The conclusion was that the F0 of mid-vowels in the languages he investigated generally falls between that of the high and low vowels, but Connell also noted many instances of mid-vowel F0 falling outside this range.

The aim of this paper is to investigate the issue of a vowel gradient with respect to IF0. For this purpose, production data were collected on eight Dutch peripheral vowels as produced by 35 native speakers of Belgian Standard Dutch.

2. MATERIALS AND METHODS

2.1. Materials

The data collection consisted of a reading task the materials of which were obtained by inserting eight Dutch peripheral vowels /i, e, E, a, A, O, o, u/ in two sets of monosyllabic words with a CVC structure. In the first set, the vowel was preceded by a voiceless labial stop and followed by a voiceless alveolar stop. This yielded the test words "Piet, peet, pet, pad, spaadt, pot, poot, spoed". In the second set, the vowels were preceded by a voiced lateral approximant and followed by a voiceless alveolar fricative. This yielded the test words "Lies, lees, les, blaas, las, los, loos, Loes". All these words were embedded in the carrier

phrase “In __ hoor je __” (In __ you hear a __). The target words were embedded in the first position, while the informants had to insert the vowel from the test word in the second position. Each sentence occurred four times in the test so that there were 64 stimuli per person (8 vowels x 2 phonetic contexts x 4 repetitions). This list was complemented by 28 stimuli which contained test words with diphthongs, rather than monophthongs. All stimuli occurred in random order.

2.2. Speakers

A total of 35 native speakers of Belgian Standard Dutch took part in the experiment. The speakers were from three different regions in Belgium, to make sure that there was a fair representation of the different speech varieties in the data collection: 12 speakers were from the East-Flanders region (Eeklo), 12 speakers from the Antwerp region (Antwerp City) and 11 speakers from the Limburg area (Hasselt). In each group, there was equal representation of men and women. The mean age of the speakers in the different geographical groups was 59, 54 and 61 years respectively. All speakers took part on a voluntary basis and were not informed about the research objectives of the experiment.

2.3. Recording procedure

The speakers were asked to read the sentences as naturally as possible and they were allowed to repeat a sentence if they were not satisfied with their pronunciation. The recordings were made in laboratory conditions by means of a TASCAM DAT recorder and an AKG head-mounted microphone.

2.4. Analysis procedures

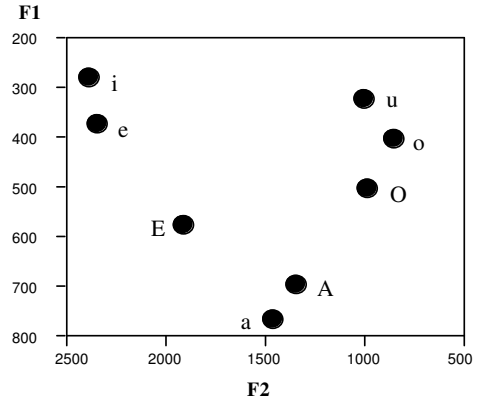
In order to measure F0, the vowels in the target words were manually selected in PRAAT [5] on the basis of a broadband spectrogram which was time-aligned with the sound wave. Subsequently, F0, F1 and F2 of each vowel were measured as the average value in the vowel’s middle third portion. The F0 analysis used PRAAT’s standard autocorrelation algorithm optimised for intonation analysis. The formants were extracted by means of PRAAT’s standard LPC-based method. The analysis conditions were set to be appropriate to female or male voices respectively. The selection of the middle third portion of the vowel and the acoustic analyses were carried out automatically by means of a script. It should be mentioned that only the vowels in the target words were analysed; the vowels which were pronounced in isolation in the second part of the carrier sentences were excluded from this study.

3. RESULTS

In this experiment, a total of 2,240 observations were obtained, i.e. 8 vowels x 2 contexts x 4 repetitions x 35 speakers.

The results of the formant measurements for the Dutch vowels are illustrated in Fig. 1, from which it can be derived that there are clear differences in the degree of opening in both the front and the back vowels.

Figure 1: Formant values (in Hz) for the recorded vowels.



The mean F0 values associated with the different vowels in the corpus as summarized in table 1.

Table 1: Average F0 values for the different front and back vowels. IF0 is defined as the F0 difference between the highest and lowest vowels and is expressed in both Hz and St.

Front vowels	F0	Back vowels	F0
i	191 Hz	u	205 Hz
e	171 Hz	o	177 Hz
E	177 Hz	O	183 Hz
a	158 Hz	A	170 Hz
IF0	33 Hz 3.28 ST	IF0	35 Hz 3.24 ST

The obtained F0 values for the different vowels were analysed by means of an ANOVA with speaker sex and region as between-subjects variables, vowel identity as a within-subject variable and F0 as the dependent variable. This analysis showed a significant effect of vowel

identity ($F(7, 2.232) = 21.5406$, $p < 0.0001$), region ($F(2, 277) = 9.733$, $p < 0.0001$) and speaker sex ($F(1, 277) = 1465.48$, $p < 0.0001$). None of the higher order interactions were significant.

In order to analyse which F0 vowel means are significantly different from each other a Tukey HSD was carried out. This analysis indicates that the average F0 of /i/ and /a/ differs significantly from each other as well as from both /e/ and /E/. The F0 difference between /e/ and /E/, however, is not significant. Applying the same analysis to the back vowels indicates that the average F0 of /u/ and /A/ differs significantly from each other as well as from both /o/ and /O/. The difference between /o/ and /O/, however, is not significant, although it can be noted that the average F0 in the open-mid vowels was slightly higher than that of the close-mid vowels.

Secondly, it was investigated how consistently the F0 values of the mid-vowels were situated between the F0 of /i/-/a/ and /u/-/A/ respectively. This was looked at for each individual speaker. From this, it appears that the F0 of the mid-vowels was outside the F0-range of the high and low vowels in only 17% of the cases. This happened more frequently in the Antwerp region than in the other regions (Antwerp: 33%; East-Flanders: 8 %; Limburg: 9%).

The second significant effect of the statistical analysis was that of geographical region. Although this dimension was not the main objective of our investigation, it is interesting to notice the average F0 in the Limburg area is significantly lower than in the other geographical areas in this study. As illustrated in table 2, this applies without exception to all the individual vowels in the corpus.

Table 2: Average F0 (in Hz) for the vowels in the different geographical regions.

Vowel	Region		
	Antwerp	East-Flanders	Limburg
i	188	203	183
e	175	177	163
E	189	185	156
a	168	160	147
u	200	217	189
o	181	182	166
O	192	194	164
A	182	174	153

Finally, it is noted that the effect of speaker sex is not significant: average fundamental frequency of the vowels for men (144 Hz) is substantially lower than in women (211 Hz). Men have an IF0 of 28.5 Hz (3.35 semi-tones), whereas the IF0 in women amounts to 38.5 Hz (2.35 semi-tones). This means that men have a smaller IF0 on a Hz-scale, while on a semi-tone scale women's IF0 is smaller.

4. DISCUSSION

This paper aimed to provide evidence as to whether there is a vowel gradient with respect to IF0. For this purpose, F0 measurements were made of the vowel realisations of 35 speakers of Belgian Standard Dutch. Eight vowels of the Belgian Dutch 12-vowel system were chosen which represent four degrees of opening in both the front and the back dimension, i.e. /i, e, E, a, A, O, o, u/.

The first relevant observation of this study is that IF0 does exist in Belgian Standard Dutch, which is indicated by the fact that there is a statistically significant difference in F0 between high and low vowels. IF0 in this study was found to be 34 Hz or 3.26 semi-tones. This value is slightly bigger than the recently reported 2.78 ST for Belgian Standard Dutch ([2]). The fact the IF0 exists in this language variety does not come as a surprise, since there is evidence of IF0 in every language that has been investigated for intrinsic vowel pitch so far. It should be mentioned, however, that these relatively large IF0-values for Dutch seem to be typical for non-tone languages.

The second result had to do with the regional differences in F0. In this connection, it was found that the average F0 of all the vowels in the Limburg region was significantly lower than in the two other regions. It is not clear what causes these systematic differences and it would be interesting to investigate this further in a more detailed experiment which also focuses on for instance differences in articulatory and laryngeal settings between the Flemish geographical regions.

The third result of this investigation was related to the sex of the speakers in the experiment. There was a significant difference in overall F0 between male and female speakers: mean F0 for men was 144 Hz and for women this value amounted to 211 Hz. This difference does not come as a surprise, since it is related to differences in larynx size between men and women. More importantly though, a clear IF0 difference was found between men and women:

IF0 of male speakers amounted to 28.5 Hz (3.57 semi-tones), whereas the IF0 in women was 38.5 Hz (2.95 semi-tones). The fact that men have a smaller IF0 on a Hz-scale and that the effect is reversed on a semi-tone scale has been reported before in [1], who indicate that these differences between the sexes may be related to lowering of the male larynx after puberty. More recent studies, however, have indicated that gender-related IF0 differences are not significant ([2]).

The fourth and main result of this study has to do with the relationship between the degree of opening/tongue height and the average F0 of the vowels. Here is was found that the F0 of mid vowels is intermediate to that of high and low vowels and that their F0 is also significantly different from that of high and low vowels. The F0 difference between the close-mid and open-mid vowels was not significant. The intermediacy of mid-vowel F0 is not only reflected in the significant statistics, but also in the consistency with which speakers realise the F0 of mid-vowels within the range set by the high and low vowels. Unlike [3], there are relatively few cases in which the F0 of the mid vowels is higher than the high vowels or lower than the low vowels: only 17% of the mid-vowels had such 'erratic' F0. From this, it can be concluded that the intermediacy of mid-vowel F0 is a very consistent feature of the data in this study in that it applies to all the participating speakers.

The intermediacy of mid-vowel F0 is consistent with the hypothesis that intrinsic vowel pitch is a consequence of articulation: in closer articulations the pull on the laryngeal system is bigger than in more open articulations and this may cause variations in F0 related to vowel height. Although the degree of opening in vowel articulation is a gradual dimension, its effect on IF0 does not seem to be one of gradience: it is sufficient to distinguish three IF0 levels, i.e. one for high vowels, one for low vowels and one for both close-mid and open-mid vowels in the absence of any significant differences between the two. This indicates that gradual articulatory changes associated with vowel articulation have a non-uniform effect on the laryngeal system through mechanical coupling.

The final observation that has to be made is that the F0 of the open-mid vowels /E/ and /O/ was quite often somewhat higher than the F0 of the close-mid vowels /e/ and /o/. Although this difference failed to show statistical significance, this was the case in 33% of all the mid vowels in this data collection. This may be related to the difference I n tenseness between these vowels: the close-mid vowels are tense, while the open-mid vowels are lax.

5. CONCLUSIONS

This investigation of average fundamental frequency of eight peripheral vowels in Belgian Standard Dutch has confirmed (once again) that IF0 exists in Belgian Standard Dutch and amounts to 3.26 semi-tones. Besides an influence of geographical region and speaker sex on intrinsic vowel F0, it is found that the gradience in the degree of openness/tongue height is only reflected to a certain extent in vowel F0: mid vowels have intermediate values between those of high and low vowels and there is no significant difference between the close-mid and open-mid vowels. This suggests that gradience in the degree of opening in vowel articulation does not correspond directly to a gradient change in F0, but that the mechanical coupling between articulation and the laryngeal system has a non-uniform effect on intrinsic vowel F0.

6. REFERENCES

[1] Whalen, D. H., Levitt, A. G. 1995. The universality of intrinsic F0 of vowels, *Journal of Phonetics 23*, 349-366.

[2] Van Hoof, S., Verhoeven, J. Intrinsic vowel F0, the size of vowel inventories and second language acquisition. Journal of Phonetics 39, 168-177.

[3] Connell, B. 2002. Tone languages and the universality of intrinsic F0: evidence from Africa, *Journal of Phonetics 30*, 101-129.

[4] Reinholt-Petersen, N. 2006. Intrinsic fundamental frequency of Danish vowels, Journal of Phonetics 6, 177-189.

[5] Boersma, P., Weeninck, D. 2006. PRAAT: doing phonetics by computer [Computer Program].