DEFYING GRAVITY: FORMANT FREQUENCIES OF ENGLISH VOWELS PRODUCED IN UPRIGHT AND SUPINE BODY POSITION

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ABSTRACT

This case study investigated the effect of body position on the first three formants (F1, F2, F3) of the British English vowels /iː/, /ɛ/, /æ/, /ɔː/ and /uː/ produced by one male native speaker. While F1 remained unaffected significant changes in F2 and F3 were found for certain vowels when they were produced in a supine rather than in an upright position. F2 was significantly lower for /iː/, /ɛ/ and /æ/ but not for /ɔː/ and /uː/ when the speaker was lying. Lowering of F3 was significant for /iː/, /æ/ and /uː/. These preliminary results obtained from one subject suggest that the posture of the speaker and hence gravity influence vowel articulation and its acoustic outcome. However, not all vowels and all formants are affected the same way.

Keywords: vowel articulation, formants, body position, gravity

1. INTRODUCTION

Normally speech sounds are produced in an upright body position. Adult talkers usually stand, walk or sit while they speak. However, in some occasions speech may also be produced in other body positions. Besides trivial examples (like e.g. a mechanic talking to his colleague while repairing a car) there are specific situations in which producing speech in a supine body position may be directly relevant for scientific research. There are certain clinical procedures and experimental methods which require the patient or subject to produce speech in a lying position rather than while sitting or standing. For many modern imaging techniques like magnetic resonance imaging (MRI), which are presently also very commonly used in the field of speech sciences [1], the subject has to be necessarily in a supine body position.

Since speech production is a very complex motoric activity that involves precise movements of the articulators and an exact timing between articulatory gestures, it may be somewhat premature to assume that changes of body positions do not have any effects on this fine-tuned motoric activity. One could argue that the direction of gravity, which changes for different body positions, may affect articulatory movements. Consequently, this might then also have an effect on the acoustic features of the produced speech sounds – unless speakers actively adapt their articulation.

There is already a considerable amount of evidence in the literature that body position do have an impact on speech production [2]–[4]. Gravity affects tongue position and tongue movements [3], [5], thickness and rounding of the lips [3], [4], the jaw [2], as well as the height of the larynx [3] and narrowing of the pharynx [4]. However, gravity seems to have different impacts on different vowels, and there are considerable differences among individual speakers [3].

Most of these studies have dealt with articulation directly and used instruments such as special MRI-scanners, which allow data acquisition in supine as well as in upright position [3] or ultrasound machines [5]. However, acoustic consequences of these articulatory changes due to different body positions have been investigated to a lesser extent and findings on this question tend to be inconsistent. For some cases significant acoustic changes have been reported [2], but results of other studies [5], [6] suggest that effects on acoustics are minimal or even negligible.

The aim of the current case study is to investigate if body position has a measurable impact on the first three formant frequencies of certain British English vowels.

2. METHOD

2.1. Material and procedure

One male native speaker of Southern British English (age = 23 years) was recorded, both in an upright (sitting) and a supine body position (lying on his back). The recordings in the upright body position were done first and after a short break the recordings in the upright position followed. All recordings took place in a soundproofed room.

The recording material consisted of 20 sentences containing 10 repetitions of each of the monosyllabic target words “beat(s)”, “bet”, “bat(s)”, “bought” and “boot(s)” for the British English vowels /iː/, /ɛ/, /æ/, /ɔː/ and /uː/. Two example sentences of the recording material are: “He lost a bet and bought himself new boots” or “She beats the bat with a stick because it wants to steal her boots”. While the immediate context was kept constant with /b/ as the onset and /t(s)/ as the coda of the syllables the position of the target words within the sentences and the surrounding words varied.

It might have certainly been beneficial to embed each target word in the same sentence frame (e.g. in the phrase “Say _ again”). However, this would have required the subject to produce 100 sentences (5 vowels x 10 repetitions x 2 conditions) in total rather than just 40 sentences. Furthermore, it was assumed that using recording material with a certain amount of variety might possible prevent the subject from falling into a monotonous speech style and therefore lead to recordings of probably more “natural” speech. In both conditions the subject was asked to read the sentences in his normal speech rate and volume.

In both experimental conditions the same material and the same recording instruments (a microphone with a clip, suitable for making recordings in different body positions without changing the distance between the speaker and the microphone, and a laptop with an USB audio interface) were used. Due to the different body positions the presentation of the material had to be slightly different. While in the upright condition the subject could read the sentences from the laptop screen, in the supine position the sentences had to be presented on a board that was hold above the head of the subject by the experimenter.

Recordings were done with the computer program Praat [7] using one channel and a sampling rate of 16000 Hz.

2.2. Acoustic analysis

After annotating the target vowels manually a fixed-frame formant analysis was performed using the computer software Speech Filing System (SFS) [8]. To find and extract the average formant frequencies for every realization of each of the five vowels a script provided within SFS was used which calculates the trimmed mean (of the central 60%) over the whole vowel segment. The trimmed mean was used because it has the benefit of neglecting possible outlier values, which may arise due to errors in the formant analysis. For two realizations of the vowel /ɛ/ the automatically extracted formant frequencies had to be corrected afterward, since the values differed extremely from other measurements for this vowel. Checking the formant track visually revealed that in these two cases the programme confused the frequencies of the formants leading to a much lower frequency for each of them. The correction of the values was done in Praat using the formant listing command and calculating the trimmed mean manually.

3. RESULTS

The following three diagrams give box plots of the first three formants for each vowel. The left box for every vowel indicates the formant frequency in the upright speaking position while the right box gives the frequency in the supine position.

Figure 1: Box plots of the frequency of the first formant (F1) of /iː/, /ɛ/, /æ/, /ɔː/ and /uː/ in upright and supine body position.

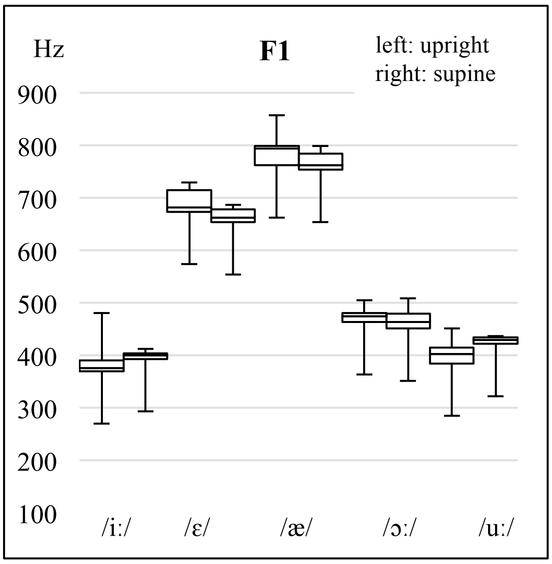


Figure 2: Box plots of the frequency of the second formant (F2) of /iː/, /ɛ/, /æ/, /ɔː/ and /uː/ in upright and supine body position.

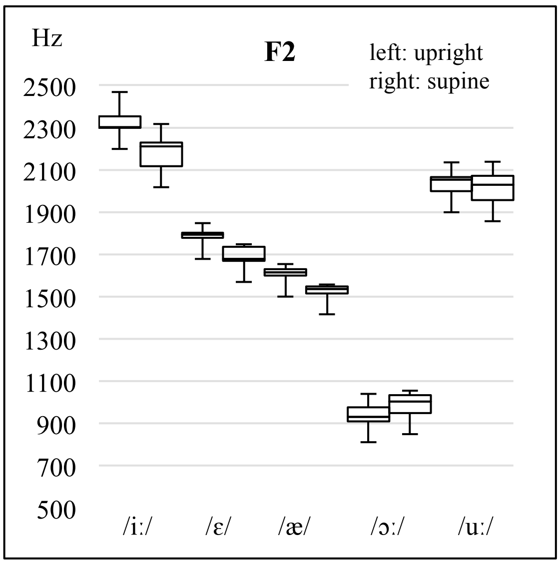
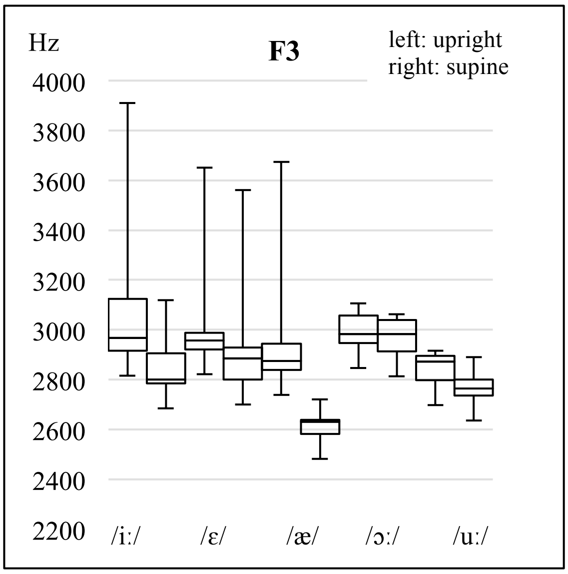


Figure 3: Box plots of the frequency of the third formant (F3) of /iː/, /ɛ/, /æ/, /ɔː/ and /uː/ in upright and supine body position.



The boxes indicate the 25th and 75th percentiles, the horizontal lines give the median and the whiskers show the minimum and maximum data points.

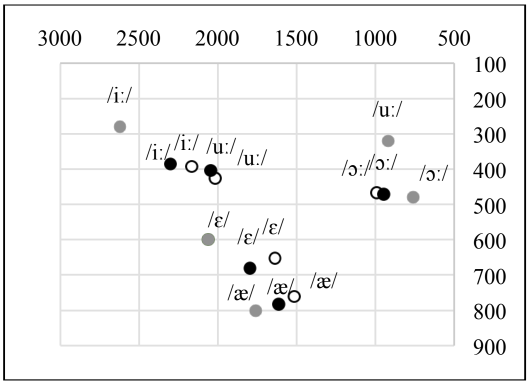
The following table summarizes the average formant frequencies of all five vowels in each condition.

Table 1: Average formant frequency (Hz) for all three formants in upright and supine body position.

		F1	F2	F3
/iː/	upright	385.6	2299.9	3114.0
	supine	393.7	2163.8	2845.0
/ɛ/	upright	681.7	1796.7	3015.1
	supine	652.6	1638.0	2909.9
/æ/	upright	782.9	1612.1	2999.6
	supine	760.4	1514.6	2603.1
/ɔː/	upright	470.4	947.3	3001.0
	supine	467.4	990.0	2964.5
/uː/	upright	403.3	2043.5	2845.2
	supine	424.8	2017.2	2769.4

Overall, the formant frequencies of our subject tend to differ somewhat from the values traditionally given for British English vowels [9]. His vowels seem to be more central resulting in a slightly smaller vowel space (see Figure 4). This might be explained by individual characteristics of the subject's vocal tract, by the recording material, as well as possibly by the speaker's age. The latter offers in particular an explanation for the extraordinary high F2 for realizations of /uː/, which reflects the fronting of this vowel typical for young speakers of British English [10].

Figure 4: Acoustic vowel space (F2 displayed horizontally, F1 vertically). Black circles indicate vowels produced in upright position, white circles vowels in supine position and grey circles show the average values for British English vowels [9].



3.1. Statistical analysis

For the statistical analysis a factorial Manova was conducted with the dependent variables F1, F2 and F3 and the independent variables "vowel" (5 levels) and "body position" (2 levels). It revealed a significant main effect of the factor "vowel" (Wilks' λ = .001, F (12, 233.118) = 233.747, p <.001) and a significant main effect of the factor "body position" (Wilks' λ = .788, F (3, 88) = 7.897, p<.001). Additionally a significant interaction between these two factors was found (Wilks' λ = .716, F (12, 233.118) = 2.616, p =.003).

Multiple comparisons (Tukey's HSD) showed that all vowels differed from each other significantly in their F1 and F2 values with the only exception of /iː/ and /uː/, for which there was no significant difference in F1. Differences in F3, on the other hand, were non-significant across all compared vowel qualities. This in in accordance with the fact that F3 values are much more similar across different vowels than F1 and F2. Therefore, F1 and F2 are considered to be the more characteristic acoustic features to distinguish different vowels.

More relevant for this study, however, is the statistically significant multivariate main effect of body position. Given the significance of the overall test, the univariate main effects were examined. Significant effects of body position were obtained for F2 (F (1, 90) = 16.475, p<.001) and F3 (F (1, 90) = 16.607, p<.001) but not for F1 (F (1, 90) = .628), p =.43, n.s.). These main effects were due to overall significantly lower F2 and F3 frequencies in supine body position than in upright body position (see Table 1).

Finally the multivariate interaction was followed up which was statistically significant for F2 (F (4,

90) = 3.999, p =.005) and F3 (F (4, 90) = 2.444, p =.052) but again not for F1 (F (4, 90) = 2.191, p =.076, n.s.).

The significant univariate interactions were also followed up. For F2 this revealed that body position had a significant effect on the vowels /iː/ (F (1, 18) = 5.622, p =.029), /ɛ/ (F (1, 18) = 7.962, p =.011) and /æ/ (F (1, 18) = 19.756, p<.001) but not on /ɔː/ (F (1, 18) = 3.006, p =0.1, n.s.) and /uː/ (F (1, 18) = .671, p =.432, n.s.). For F3 the body position had a significant effect on /iː/ (F (1, 18) = 5.548, p =.03), /æ/ (F (1, 18) = 15.486, p =.001) and /uː/ (F (1, 18) = 6.192, p =.023, n.s.) but not on /ɛ/ (F (1, 18) = .517, p =.481, n.s.) and /ɔː/ (F (1, 18) = .934, p =.347, n.s.)

4. DISCUSSION

The results of this case study suggest that body position does have an impact on formant frequencies of British English vowels. However, not all formants and all vowels were affected the same way. F1 did not differ significantly between upright and supine body position, whereas F2 and F3 did. Furthermore, the factor body position interacts with the factor vowel. Only for /iː/, /ɛ/ and /æ/ F2 was significantly lower in the supine position. For F3 the effect of position was only significant for /iː/, /æ/ and /uː/.

The result that F1 was not significantly affected by body position could probably be explained by the fact that F1 mainly corresponds to the "openness" of the articulation (tongue height). It could be that this articulatory feature is less affected by changes of body position from a sitting to a lying position, although there are also other findings in the literature [2]. The overall results for F2, however, are in accordance with previous findings that the tongue is retracted in a lying position [3]. Since F2 correlates with the "backness" of vowel articulation it seems reasonable that these F2-changes are the result of a retracted tongue due to gravitation. However, in the current study not every vowel was affected, since the upright/supine F2 values did not differ for /ɔː/ and /uː/. These results are somewhat contradictory to previous findings indicating that in supine position back vowels are more retracted than front vowels [3].

It is tempting to explain the different results between vowels by the difference in the place of articulation. /iː/, /ɛ/ and /æ/ are front vowels whereas /ɔː/ and /uː/ are normally considered to be back vowels. One could therefore argue that body position does not affect the F2 values of back vowels, maybe because they are already produced backwards in the mouth and thus the supine body position does not have an additional effect. The problem with this explanation is though that the realizations of /uː/ produced by our subject did not seem to be actual back vowels. His [uː]s all had very high F2 frequencies indicating an extreme fronting of this vowel. However, there are different ways to achieve a "fronting" of /uː/. Beside a change of tongue position it might also be that the speaker does not round his lips, which would also lead to "fronting". Unfortunately, in the current study the articulatory movements of the speaker during the recording session have not been monitored. So, we do not know if the speaker rounded his lips or not. However, it can be assumed, that our subject's realizations of /uː/ included a fronted tongue position, since it has been report that fronting of British /uː/ is really achieved by changing the tongue position rather than sole changes of lip rounding [11].

Another possible explanation for the resistance of /ɔː/ and /uː/ to the effects of body position may be found in the rounding of these two vowels. It could be that in supine body position the lips are less rounded [3] which could cancel out the effect of the retracted tongue, resulting in a non-significant F2-change for these two vowels.

Overall, it seems as if body position has a complicate influence on vowel articulation. This is also indicated by the fact that F3 was also affected by body position, but only in case of /iː/, /æ/ and /uː/.

Hence, it would be interesting to investigate, why certain vowels are affect by body position and certain not, and whether these single-subject findings for British English vowels are robust. Additionally, it might be interesting to examine speech production in other body positions, such as in a headstand. It might be that in this position tongue height (F1) is more affected than backness (F2) of articulation, since the direction of gravity would be the same for the backness-dimension of the tongue. Another interesting research question would be whether disturbing the auditory feedback of the speaker has an influence on the effect of body position on speech production. Not least this would be an important question considering the noisy environment in MRI-scanners.

5. CONCLUSIONS

The results of this case study, although preliminary, suggest that speech produced while lying may not exactly be the same – articulatorily and acoustically – as "normal" speech. This should be taken into consideration when interpreting findings from MRI studies, which offer a unique opportunity to gain insights into the vocal tract during speech production but usually require a supine body position of the speaker.

6. REFERENCES

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