THE INFLUENCE OF STRESS ON V-TO-V COARTICULATION: AN ELECTROPALATOGRAPHIC STUDY

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ABSTRACT

The aim of this study is to examine variability in V-to-V transconsonantal coarticulatory effects as a function of stress. Previous studies have documented greater coarticulatory effects of the stressed vowel on the unstressed suggesting that the unstressed vowel is coproduced more with the neighbouring stressed vowel. Evidence of such coarticulatory behaviour is examined using articulatory data recorded with the technique of electropalatography (Reading EPG system). The speech material consisted of Greek disyllabic real words containing Vowel-Consonant-Vowel (VCV) sequences with V = /i, a/ and C = /p,t,s/. Stress placement was on V1 or V2. The results provided evidence of greater coarticulatory effects of the stressed vowel on the unstressed vowel in both the anticipatory and carryover directions. However, these effects were not uniform but were systematically modified by factors such as the identity of the intervocalic consonant and speaker-specific strategies.

1. INTRODUCTION

Literature studying the influence of stress on coarticulation has provided evidence that stressed vowels resist coarticulation more than unstressed vowels [1]. Unstressed vowels show greater gestural overlap with neighbouring stressed vowels.

Fowler [1] conducted an acoustic study on coarticulation in stressed and unstressed vowels. She examined coarticulatory effects in differentially stressed nonsense trisyllabic stimuli of the form V1bV2bV3 where the middle vowel was stressed or unstressed. The results revealed greater effects of the stressed vowels on the medial unstressed vowel than of the unstressed vowels on the medial stressed vowel. In addition, greater carryover than anticipatory coarticulatory effects of the stressed flanking vowels on the medial unstressed vowel were found.

Data supporting Fowler's predictions are reported by Magen [2] who examined the effect of stress on V-to-V coarticulation in 'VbV and V'bV sequences in English. Her results revealed stress influence on the extent of coarticulation with anticipatory effects starting later in a stressed than unstressed vowel and carryover effects decreasing sooner in a stressed than unstressed vowel.

However, further research has additionally emphasised the importance of contextual effects on coarticulation and has suggested that stress effects are moderated by contextual differences [3, 4].

In particular, Farnetani et al. [3] examined the influence of stress on coarticulation in /'tV1tV2/ and /tV1'tV2/ sequences (V=i, a, u) in Italian using electropalatography. Their results showed that stressed vowels always influenced the transconsonantal unstressed vowels while unstressed vowels induced effects on stressed vowels only in the carryover direction. These latter effects depended however on the identity of the vowels. The authors concluded that coarticulation depends on both stress and the identity of the segments involved.

Data reported by Huffman [4] also emphasise the primacy of contextual effects on coarticulation. The author examined acoustically the influence of stress on V-to-V coarticulation in VCV sequences (with C=/d, l/ and V=/i, a, u, ★/) and /bVC★CVb/ sequences (with C=/d, l/ and V = /i, a, u/). Stress placement was on the first or second vowel in the VCV sequences (/★/ was only used in unstressed positions). In the /bVC★CVb/ sequences, there was one primary and one secondary stress on either V1 or V3. Her results revealed small stress effects on coarticulation. She reported minimal stress effects on V-to-V coarticulation over /d/ and /l/ although effects were more common over /l/. Where there was evidence of stress effects, however, these were in agreement with the findings reported by Fowler [1, 5], i.e., stressed vowels exert stronger effects on the transconsonantal vowel than unstressed ones. Huffman also reported significant context effects on the amount of V-to-V coarticulation. In particular, coarticulatory effects varied as a function of the intervocalic consonant and stress effects were moderated by the consonantal differences.

The aim of this paper is to study the influence of stress on V-to-V coarticulation in VCV sequences with intervocalic /p,t,s/, i.e., consonants differing in the degree of articulatory constraint involved in their production and thus predicted to influence transconsonantal coarticulatory behaviour differentially. The influence of stress and context on the resulting coarticulatory patterns is examined. Evidence from a further language, i.e., Greek, may provide useful insights on the role of these factors on coarticulation.

2. METHODOLOGY

2.1. The speech material

The speech material consisted of disyllabic real words containing VCV sequences with V = /i,a/ and C = /p,t,s/. All possible combinations were recorded. Two stress conditions and utterance types were included in the corpus. In a segmentally identical sequence, stress placement was on V1 or V2 (e.g., /'pata/ vs. /pa'ta/). All items were produced in isolation and embedded in short sentences. The speech material was repeated ten times by two Greek speakers, CN and JM, at a comfortable speaking rate.

2.2. Data acquisition and analysis

Data was acquired with the technique of electropalatography (Reading EPG system) which records lingual contact with the palate in continuous speech [6]. Simultaneous acoustic data were also recorded. For the analysis of V-to-V effects, six annotation points were identified on the acoustic data. Onset of V1 (v1o) and V2 (v2o), end of V1 (v1e) and V2 (v2e), temporal midpoint of V1 (v1m) and V2 (v2m). The articulatory analysis was based on the EPG frames at these points.

Data reduction was carried out with two contact distribution indices, i.e. the anteriority and centrality index [7]. The anteriority index can be used as a measure of lingual forwardness and the centrality index as a measure of lingual raising. These indices were used because they provide a precise measure of anterior and central lingual placement and can capture both the degree and distribution of lingual contact with the palate. The use of both indices is advantageous since they provide a two dimensional description of contact as opposed to commonly used measures such as the 'totals' which provide information on the degree of contact only. The indices can efficiently reveal gross differences in tongue placement between, e.g., consonants articulated at different places of articulation (e.g., alveolar vs. postalveolar vs. palatal). They can also reveal more subtle differences between, e.g., the same segment in two different stress conditions or utterance types.

For the study of V-to-V coarticulatory effects, the influence of the /i/ vowel on the /a/ vowel was examined in the sequences /aCa-aCi/ and /aCa-iCa/ to capture anticipatory and carryover coarticulatory effects respectively. The influence of /a/ on /i/ was examined in the sequences /iCi-iCa/ (anticipatory) and /iCi-aCi/ (carryover). For the anticipatory effects, the indices were calculated at the v1o, v1m and v1e points and for the carryover effects at v2o, v2m, v2e.

Factorial ANOVA analyses were conducted on the index differences at each point in the relevant sequences (e.g., the index difference at the three points of V1 = /a/ in the sequences /'apa-'api/, /'asa-'asi/, and so on) with subject, consonant, stress and utterance type as factors. The results may be positive or negative; positive values provide evidence of coarticulatory effects while negative values suggest presence of dissimilative behaviour. For instance, the anteriority index of the first /a/ of /ata/ is subtracted from the anteriority index of the /a/ of /ati/ and a positive difference suggests increased anteriority for the /a/ of /ati/ due to the following front vowel /i/. On the other hand, a negative difference suggests a more retracted vowel in the environment of V2 = /i/ providing evidence of dissimilative behaviour.

Due to lack of space, in the results section below the differences of the indices means at the vocalic midpoint (v1m or v2m) will only be provided for the different analyses.

3. RESULTS

3.1. Anticipatory effects

3.1.1. The sequences /aCa-aCi/. The stress influence on anticipatory V-to-V effects varied as a function of the intervocalic consonant. In general, greater anticipatory effects were found from the stressed vowel on the unstressed over the consonants /p/ and /s/ only.

In particular, with reference to anteriority, the consonant by stress interaction (v1o: $F(2, 239)=4.22$ $p<0.0160$; v1m: $F(2, 239)=4.15$ $p<0.0171$; v1e: $F(2, 239)=3.26$ $p<0.0402$) showed that at the first two vocalic points, anticipatory effects were found only in the V2 stress condition over /p/ and /s/. Effects over /t/ were of similar degree in both stress conditions. At the end point, variability was observed in the degree of effects over the three consonants as a function of stress. It is interesting to note that at v1o and v1m anticipatory effects are generally blocked over /p/ and /s/ in the V1 stress condition while over /t/ the data suggest presence of coarticulatory effects in both stress conditions.

With reference to lingual raising, greater effects in the V2 stress condition over /p/ and /s/ were also evident (consonant by stress interaction: v1o: $F(2, 239)=27.44$ $p<0.0001$ and v1m: $F(2, 239)=15.30$ $p<0.0001$). Small negative effects were present in the V1 stress condition over /p/. Over /t/ effects were greater in the V1 stress condition at v1o; at v1m effects were negative in both stress conditions. The subject by consonant by stress interaction, (v1o, v1m: $p<0.0001$), shows similar tendencies for both subjects although the degree of effects and the differences between stress conditions were very small for speaker JM.

Anteriority	**p**	**t**	**s**
V1 stress	-0,003	0,017	-0,003
V2 stress	0,039	0,015	0,022
Centrality	**p**	**t**	**s**
V1 stress	-0,015	-0,008	0,020
V2 stress	0,053	-0,023	0,039

Table 1. Anteriority and centrality index mean differences of V1=/a/ in /aCa-aCi/ (C=p,t,s) in the two stress conditions at v1m.

3.1.2. The sequences /iCi-iCa/. Similarly to the /aCa-aCi/ sequences, the stress influence on V-to-V anticipatory effects varied as a function of the intervocalic consonant. Generally greater anticipatory effects in lingual anteriority were found from the stressed vowel on the unstressed over the consonants /p/ and /s/ only. For lingual raising, stress effects were more variable over the three consonants and between speakers.

In particular, with reference to anteriority, the consonant by stress interaction (v1o: $F(2, 239)=25.72$ $p<0.0001$, v1m: $F(2, 239)=6.52$ $p<0.0018$, v1e: $F(2, 239)=6.51$ $p<0.0018$) revealed that anticipatory effects were greater when V2 was stressed over /p/ and /s/; small negative effects in the V1 stress condition over /p/ were present at v1o and v1m. Over /t/, positive effects in the V1 stress condition and negative effects in the V2 stress condition were evident at v1o and v1e. Negative effects in both stress conditions were present at v1m.

Anteriority	**p**	**t**	**s**
V1 stress	-0,01	-0,015	0,003
V2 stress	0,052	-0,035	0,043

Table 2. Anteriority index mean differences of V1=/i/ in /iCi-iCa/ (C=p,t,s) in the two stress conditions at v1m.

With reference to lingual raising, large variability was observed as a function of the speaker and the consonantal environment (subject by consonant by stress interaction: v1o: $F(2, 239)=5.91$ $p<0.0032$, v1m: $F(2, 239)=5.80$ $p<0.0035$, v1e: $F(2, 239)=4.17$ $p< 0.0167$). Over /p/, greater effects in the V2 stress condition were evident for CN and in the V1 stress condition for JM. Over /t/, effects were positive in the V1 stress condition for both subjects at all points while in the V2 stress condition effects were smaller or negative. Large variability between speakers and points in time was evident in the effects over /s/.

Centrality	Speaker	p	t	s
V1 stress	CN	-0,003	0,032	0,038
V2 stress		0,081	-0,051	0,017
V1 stress	JM	0,041	0,050	0,021
V2 stress		-0,001	0,004	0,043

Table 3. Centrality index mean differences of V1=/i/ in /iCi-iCa/ (C=p,t,s) in the two stress conditions for speakers CN, JM at v1m.

3.2. Carryover effects

3.2.1. The sequences /aCa-iCa/. The stress influence on V-to-V carryover effects also varied as a function of the intervocalic consonant. Greater carryover effects in anteriority were systematically found from the stressed vowel on the unstressed over the consonant /p/ only. In addition, for lingual raising, carryover effects over /p/ were only present from the stressed vowel on the unstressed.

In particular, regarding anteriority, the subject by consonant by stress interaction (v2o: $F(2, 239)=22.77$ $p<0.0001$, v2m: $F(2, 239)=10.34$ $p<0.0001$; v2e: $F(2, 239)=7.53$ $p<0.0007$) showed that effects over /p/ were greater in the V1 stress condition for both subjects. Over /t/, effects were generally negative in both stress conditions (with exceptions at v2o) and their degree varied between subjects. Over /s/, greater effects in the V1 stress condition were found for JM; CN generally showed positive effects in the V2 stress condition but negative when stress fell on V1.

Regarding lingual raising, large variability in the influence of stress on carryover effects was revealed by the subject by consonant by stress interaction (v2o: $F(2, 239)=6.16$ $p<0.0025$, v2m: $F(2, 239)=7.35$ $p<0.0008$, v2e: $F(2, 239)=8.23$ $p< 0.0004$). Presence of carryover effects in the V1 stress condition was evident over /p/. Large negative effects in the V2 stress condition were found for CN. Over the fricative /s/, effects were generally blocked at v2o, v2m for CN and v2m for JM. Greater positive or negative effects in the V1 stress condition were evident at the other points. Effects over the plosive /t/ were negative for both subjects in both stress conditions. Speaker JM showed however generally small negative effects while for CN large negative effects over /t/ were present.

Anteriority	Speaker	p	t	s
V1 stress	CN	0,035	-0,109	-0,057
V2 stress		0,002	-0,16	0,051
V1 stress	JM	0,051	-0,087	0,067
V2 stress		0,021	-0,081	0,02
Centrality	**Speaker**	**p**	**t**	**s**
V1 stress	CN	0,046	-0,121	-0,006
V2 stress		-0,081	-0,115	0,003
V1 stress	JM	0,019	-0,012	0,009
V2 stress		0,006	-0,013	-0,002

Table 4. Anteriority and centrality index mean differences of V2=/a/ in /aCa-iCa/ (C=p,t,s) in the two stress conditions for speakers CN and JM at v2m.

3.2.2. The sequences /iCi-aCi/. Similarly to the /aCa-iCa/ sequences, generally greater anticipatory effects in lingual anteriority were systematically found from the stressed vowel on the unstressed over the consonant /p/ only. Effects in lingual raising were more variable.

In particular, with reference to anteriority, the influence of stress varied as a function of the speaker and the consonant. The subject by consonant by stress interaction (v2o: $F(2,239)=8.91$ $p<0.0002$, v2m: $F(2,239)=8.19$ $p<0.0004$, v2e: $F(2, 239)=5.45$ $p<0.0049$) showed that the difference in carryover effects due to stress was generally greater for JM than CN, especially over /p/. Effects were generally greater in the V1 stress condition over /p/ for both speakers and over /s/ for JM. A different tendency in the sequences with /s/ produced by CN in connected speech was evident; greater effects in the V2 stress condition were present (subject by consonant by stress by utterance interaction: v2o, v2m: $p<0.0001$; v2e: $p<0.0103$). Effects over /t/ were negative and smaller in the V1 stress condition at v2m and v2e.

With reference to lingual raising, the subject by consonant by stress interaction (v2o: $F(2,239)=9.12$ $p<0.0002$, v2m: $F(2,239)=11.30$ $p<0.0001$, v2e: $F(2,239)=10.73$ $p<0.0001$) shows that for speaker JM greater effects in the V1 stress condition occur in the environment of /p/ and /t/ (except at v2o for /t/). Greater positive or negative effects are present in the V2 stress condition over /s/. Larger variability is evident in the effect of stress on carryover effects for speaker CN. Positive effects in the V2 stress condition and negative in the V1 stress condition are evident over /s/. The opposite occurs over /t/, while over /p/ small and variable differences between stress conditions were evident at the different points.

Anteriority	Speaker	p	t	s
V1 stress	CN	0,125	-0,013	-0,017
V2 stress		0,064	-0,081	0,034
V1 stress	JM	0,298	-0,049	0,048
V2 stress		0,1	-0,088	0,001
Centrality	**Speaker**	**p**	**t**	**s**
V1 stress	CN	0,016	0,011	-0,059
V2 stress		0,009	-0,124	0,063
V1 stress	JM	0,150	0,071	0,006
V2 stress		0,027	0,002	0,021

Table 5. Anteriority and centrality index mean differences of V2=/i/ in /iCi-aCi/ (C=p,t,s) in the two stress conditions for speakers CN and JM at v2m.

4. DISCUSSION

Although the examination of stressed induced V-to-V coarticulatory influences spanning a consonant provided evidence of coarticulatory effects from the stressed vowel on the unstressed vowel in both the anticipatory and carryover directions, these effects were not uniform but were modified by factors such as the identity of the intervocalic consonant and speaker-specific strategies. In addition, with reference to the utterance type variable examined in the study, the data showed that the stress influence on coarticulation was generally similar in the words produced in isolation and embedded in sentences.

Relative systematicity in the stress influence on coarticulatory behaviour over the bilabial /p/ was revealed. Coarticulatory effects in lingual anteriority were more systematic than in lingual raising. For both the /apa-api/ and /ipi-ipa/ sequences, anticipatory effects in anteriority and raising were found when stress placement was on the second vowel, i.e., from the stressed on the unstressed vowel. On the contrary, anticipatory effects of the unstressed on the stressed vowel (i.e., stress placement on V1) were generally blocked. This is in agreement with Fowler [1] who reports that coarticulatory effects of stressed vowels on neighbouring unstressed vowels are larger than effects of unstressed vowels on neighbouring stressed ones. The only exception to this pattern was for lingual raising in the pairs with fixed /i/ (i.e., /ipi-ipa/), for which one of the subjects showed greater effects from the unstressed vowel on the stressed (i.e., when stress was on V1).

Similar behaviour was observed for the carryover effects in the sequences /apa-ipa/ and /ipi-api/. V-to-V coarticulatory effects in both lingual anteriority and raising were observed when stress placement was on the first vowel, i.e., from the stressed vowel on the unstressed. Effects from the unstressed vowel on the stressed (stress placement on V2) were generally blocked. Similarly to the anticipatory direction, effects in lingual raising were more variable. For the sequences with fixed /a/ (i.e., /apa-ipa/), large negative effects when stress placement was on V2 were found for one subject. In agreement with Magen [8], this is interpreted as evidence of overshoot and occurs as articulators move from very different vocal tract positions. It is interesting to note that in a separate analysis of lingual placement during the vowels in the symmetrical sequences /iCi/, CN showed more raised lingual placement for the unstressed pre-consonantal /i/ in the environment of the bilabial compared to JM; this finding combined with a more peripheral production for the stressed /a/ suggests the presence of a large distance between the two vowels.

The stress effect on coarticulatory tendencies over the fricative /s/ was also relatively systematic in the anticipatory direction and similar to the behaviour observed over the bilabial. For both the /asa-asi/ and /isi-isa/ sequences, greater anticipatory effects in anteriority and raising were generally found from the stressed on the unstressed vowel. Effects were smaller or completely blocked from the unstressed vowel on the stressed. Some variability between subjects and during time was however observed. For instance, for lingual anteriority in the pairs with fixed /a/ (i.e., /asa-asi/), effects were negative in both stress conditions at the endpoint of the vowel. This tendency may be due to the increasing influence of the consonantal constriction at the vocalic boundary. In the carryover direction, large variability between the subjects and during time was however observed in both lingual anteriority and raising. Interestingly, instances of both greater effects from the stressed vowel on the unstressed (e.g., for subject JM) or from the unstressed vowel on the stressed (e.g., for subject CN) were found. In addition, dissimilative effects as a function of stress were observed.

The stress influence on coarticulatory tendencies over the plosive /t/ was interestingly different, in part due to the frequent presence of large negative effects. In the anticipatory direction, although there was large variability, commonly greater coarticulatory effects from the unstressed vowel on the stressed were observed. In the carryover direction, for the sequences with fixed /a/ (i.e., /ata-ita/), large dissimilative effects were found for both lingual anteriority and raising in both stress conditions. These effects were generally larger when V2 was stressed. In the pairs with fixed /i/ (i.e., /iti-ati/), dissimilative effects in anteriority were also generally present. However, for lingual raising in general coarticulatory effects were found from the stressed vowel on the unstressed.

Our results, therefore, come in partial agreement with the findings reported by Fowler [1,5] where stronger transconsonantal V-to-V effects were found from the stressed vowel on the unstressed than vice versa. Stress effects on V-to-V coarticulation generally followed this pattern when the intervocalic consonant was a bilabial (similarly to Fowler [1]) and thus the V-to-V gesture was not affected by a lingual consonantal gesture but was left free to coarticulate. Magen [2] also reported stronger or more extensive effects on unstressed than stressed vowels in VbV sequences. However, in the environment of the coronal consonants the stress influence on V-to-V effects was variable suggesting that context is a major determinant of coarticulatory behaviour and that stress effects may affect this process in conjunction with context effects which determine coarticulatory patterning. Huffman [4, p. 46] reached a similar conclusion reporting that the degree of articulatory constraint on tongue body movement was one of the strongest factors affecting V-to-V coarticulatory behaviour and that stress effects were moderated by these contextual differences. In addition, Farnetani et al. [3] reported that some stress-induced effects depended on the identity of the segments involved and concluded that stress effects can interact to strengthen or weaken coarticulatory effects.

Finally, our data have clearly indicated that individual strategies contribute to further variability in the overall coarticulatory patterns. An interesting related finding was that there was greater variability present in lingual raising than anteriority. Such variability may relate in part to differences in palatal shape which may in turn partially relate to the different strategies adopted by speakers [9].

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