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COARTICULATION IN HEARING AND DEAF TALKERS

by

ARETI OKALIDOU

A dissertation submitted to the Graduate Faculty in Speech and Hearing Sciences
in partial fulfillment of the requirements for the degree of Doctor of Philosophy,
the City University of New York.

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THE CITY UNIVERSITY OF NEW YORK

Abstract

Coarticulation in hearing and deaf talkers

by

Areti Okalidou

Adviser: Professor Katherine Harris, Ph.D.

Research in speech production of deaf individuals has yielded incomplete and conflicting findings regarding coarticulation.

In this study, two experiments were conducted to compare the coarticulatory patterns of three prelingually deafened, orally-trained adults and three hearing controls. In the first experiment, the effect of context on vowels was assessed. F1 and F2 measurements were made on the vowel center of point vowels produced by hearing and deaf talkers in two speaking conditions, namely, in isolation and in context (b_b and d_d). In the second experiment, F2 measurements and temporal measurements were taken at specified intervals in disyllables /ə#CVC/ where the vowel context was [i], [u], [a], and the consonant context was either b_b or d_d. Talkers uttered the disyllables in a carrier phrase "____ again" at two speaking rates, normal and fast.

Findings indicated that

a) For the hearing talkers the widest distribution of vowels occurred in the isolated condition whereas for the deaf talkers it occurred in the context-embedded conditions. As has been reported previously, in all conditions, the vowel space of the deaf talkers was reduced relative to that of the hearing talkers.

b) Different patterns of anticipatory coarticulation of vowel occurred in the deaf vs. the hearing talkers depending on the phonetic context. The hearing talkers showed greater anticipatory coarticulation of vowel than the deaf talkers in /∂bVb/ disyllables. The deaf talkers showed greater anticipatory coarticulation of vowel than the hearing talkers in /∂dVd/ disyllables.

c) The hearing talkers showed greater anticipatory coarticulation of consonant context in /∂bVb/- /∂dVd/ pairs than the deaf talkers.

d) The patterns of anticipatory coarticulation of vowel and consonant segments in the hearing vs. the deaf talkers did not change with changes in speaking rate.

e) Vowel separation was associated with the amount of anticipatory coarticulation for the hearing but not for the deaf talkers.

f) No relationship between vowel distribution and intervocalic coarticulation was shown across talkers differing in hearing status nor for any particular deaf talker.

It was concluded that the speech of the hearing and the deaf talkers is guided by different patterns of articulatory organization.

Acknowledgments

The number of people that have contributed to the development and completion of this thesis could have easily staged a Broadway performance. I would have not been able to start nor achieve any of my educational goals without the assistance of Dr. Irving Hochberg, the Executive Officer of the Speech & Hearing Sciences Program, who has provided me with the financial support needed throughout my stay in the program..

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STATEMENT OF THE PROBLEM

In this study, "deaf talkers" are subjects who were orally trained and had sustained prelingual hearing losses whose magnitude did not enable them to acquire speech by hearing alone.

It is known that the speech of individuals who suffer a prelingual, profound hearing loss is less intelligible than that of normals. One cause of the problem is that deaf talkers differ from hearing talkers in the timely orchestration of articulatory movements in running speech (Calvert, 1962).

Most of the studies on the speech patterns of deaf individuals have focused on static measures of their speech. On the other hand, the very few studies in the area of coarticulation, that is, coordination of phonetic segments in running speech, have yielded inconsistent results. Most of these studies suggest that coarticulation is reduced in deaf talkers. However, there is some evidence in the literature that indicates that coarticulation is sometimes increased.

In this study, a detailed investigation of coarticulation in /∂bVb/ and /∂dVd/ disyllables in deaf talkers was undertaken in order to

a) uncover more information about the coarticulatory patterns of deaf talkers than the literature supplies.

b) provide insights into what might account for the kinds of coarticulatory differences seen in deaf vs. hearing talkers.

On the basis of the literature, two major factors can be proposed to account for the decreased coarticulation in the speech of deaf talkers:

1) the durational differences between deaf and hearing talkers' speech. As is known, (McGarr & Osberger, 1982; Osberger & Levitt, 1979) the speech of deaf talkers is usually slower than the speech of the hearing. Hence, deaf talkers may show a reduced articulatory overlap between segments.
2) the differences of vowel systems between deaf and hearing talkers. The vowel space is more collapsed in deaf than hearing talkers, that is, vowels are more similar to each other. Thus, the spectral differences between upcoming vowels might appear smaller due to the smaller spectral differences between their centers. With respect to the manifestations of vowel system structure in running speech (Manuel & Krakow, 1984), a compressed vowel space would allow less vowel-to-vowel coarticulation.

One factor that may partly account for the mixed results in the coarticulation literature for deaf talkers is that various studies have used different contexts. Some studies have examined production of CV sequences where a single articulator (usually the tongue) was involved for the production of both consonant and vowel gestures. Other studies have used CV sequences where the productions of consonant and vowel gestures were made by two separate articulators (usually lips and tongue). It should be noted that a similar confusion in findings for coarticulation exists in the literature of developing speech, where different investigators have used different speech materials. For example, Nittrouer, Studdert-Kennedy & McGowan (1989), studying sibilant-vowel utterances, found greater coarticulation at vowel onset in children than adults. Goodell & Studdert-Kennedy (1993), for bilabial-vowel utterances, found greater overlap at vowel onset for adults than children.

In the present study, we have attempted to study the role of various factors in accounting for the coarticulatory differences between hearing and deaf talkers by 1) manipulating speaking rate to test whether coarticulation is increased by faster speaking rates in the two groups and whether coarticulation is comparable in deaf and hearing talkers at similar segment durations 2) examining coarticulation as a function of vowel separation in the two groups 3) comparing coarticulation in CV contexts which consist of both bilabial-vowel and alveolar-vowel utterances.

BACKGROUND

Before reviewing the studies on the speaking patterns of deaf individuals, it is necessary to consider the literature findings in the speech of normals. Segmental, crosslinguistic and suprasegmental aspects of spatio-temporal organization of running speech are discussed.

With respect to the organization of segmental structure in running speech, studies have provided conflicting accounts on the extent of anticipatory coarticulation and, in particular, the issue of planning. Two classes of models, extrinsic and intrinsic, have been developed to describe the phenomenon of coarticulation, which is defined here as the mutual articulatory/acoustic influences between a segment and its surrounding context. Extrinsic models described anticipatory coarticulation as a planned event where spatial signatures of phonemes in a C_nV string (where C_n = a string of consonants, C_1 C_2 C_3 C_4..C_n) altered to accommodate nonconflicting, phonetic features of upcoming phonemes, such as lip rounding models (Kozhevnikov & Chistovich, 1965; Henke 1966). In the Kozhevnikov & Chistovich model, phonetic features spread within the articulatory unit of organization, the C_nV, regardless of morpheme boundaries and number of consonants involved. Henke (1966) posed a "look-ahead" or "feature-spreading" model where phonetic features of a phoneme occurring later in a string migrate to preceding phonemes that do not carry conflicting feature specifications.

The extent of anticipatory coarticulation is solely determined by conflict in the cooccurring features of a phoneme. Both models, entail a common assumption. Temporal spread of articulatory modifications is planned, therefore, divorced from inherent properties of phonological structure.

Intrinsic models, or alternatively, coproduction models of coarticulation view timing as an intrinsic component of phonological structure (Fowler, 1980; Bell-Berti & Harris, 1981; Browman & Goldstein, 1986). Segments are composed of one or more articulatory gestures which overlap in time during running speech. In coproduction models, temporal and spatial coordinates covary during the enactment of invariant underlying segment representations. The most explicit account of intrinsic class models is provided by "frame" theory (or temporal model) of coarticulation where coarticulation is viewed as the mechanical outcome of articulatory movement and its coordination (Bell-Berti & Harris, 1981; 1982). The extent of coarticulation is not planned but is rather temporally confined to the coproduction of neighboring segments. Frame theory poses three timing rules for coproduction of neighboring segments: a) "The articulatory period of a segment is longer than its acoustic period." b) "For a given articulator, the period of anticipation is temporally independent of the preceding phone string length, if there is no articulatory conflict." c) "The articulatory period may begin at different times for different articulators."

A series of EMG provided strong evidence in support of the coproduction account and "frame" theory in particular studies (Bell-Berti & Harris, 1979, 1982; Gelfer, Bell-Berti & Harris, 1989). Bell-Berti & Harris (1974; 1979; 1982) have clearly shown that the onset of lip-rounding activity for /u/ in /VC_nu/ (i.e V = vowel, C_n = a string of consonants) strings is not dependent on the number of preceding consonants or their duration in the syllable string (Daniloff & Moll, 1968; Moll & Daniloff, 1971; Benguerel & Cowan, 1974; Sussman & Westbury, 1981), but that it is tied temporally to the acoustic onset of that vowel. Gelfer, Bell-Berti & Harris (1989) have shown that the apparently conflicting results among EMG studies can be reliably attributed to flaws of the experimental design and overeliance on traditional phonetic description of individual phonemes. In the Gelfer et. al. study, EMG and movement data were analyzed to examine lip rounding activity in minimally contrastive pairs, /iC_ni/ vs. /iC_nu/, where C_n was either /t/ or /s/ or a consonant string which contained some combination of the two, up to four consonants. Results have indicated that lip rounding occurred in /iC_ni/ utterances where, according to traditional phonetic description, none of the phonemes carry such feature specification. Thus, it was shown that any correlations between consonant string duration and onset of EMG activity for lip rounding for /u/ was accidental and occurred because of theoretically unanticipated lip rounding of preceding phonemes in a string.

In agreement with the coproduction account delineated above, Öhman's (1966) acoustic study has long established that the temporal domain of the anticipation of a stressed vowel does not extent beyond the offset of the preceding vowel in a VCV utterance. Cinefluographic (Gay, 1974) and EMG (Bell-Berti & Harris, 1979) studies have also shown that anticipatory vowel effects do not generally extend across the consonant to the preceding vowel. Gay demonstrated that in /pV_1CV_2p∂/ utterances the target positions of the first vowel are not altered by the identity of the second vowel (/i/, /a/, /u/) in any of three consonant contexts, /p/, /t/, and /k/. Bell-Berti & Harris (1979) investigated the activity of the genioglossus muscle during /i/ and /u/ productions in /∂pVCVp∂/ utterances where C was either /p/ or /k/ and stress was assigned to either the first or the second vowel. They found evidence of vowel-to-vowel anticipatory effects in only 25 % of the cases.

However, a great bulk of coarticulatory phenomena can be accounted for by the notion of gestural antagonism. It appears that the gestural activity for a stressed vowel can extend across the transconsonantal boundary into the preceding vowel provided that the formed gestural overlap does not result in articulatory conflict. Thus, in a bilabial consonant context, the anticipatory effects of the stressed vowel extend to the preceding vowel when the latter is neutralized (schwa). Alfonso and Baer (1982), analyzed ten different vowels uttered in a /∂pVp/ context by a single speaker, using simultaneous measurements of movement data (lateral cinefluorography), EMG data (genioglossus muscle) and acoustic data. Their movement data indicated that tongue dorsum horizontal movements for back vowels began much earlier (350+ msec) than the onset of voicing of the stressed vowel. This finding is supported by an earlier EMG for the same talker, in a similar utterance frame, where the activity of the styloglossus muscle for back vowels begun at least 500 msec before the onset of voicing study (Raphael & Bell-Berti, 1975). Recasens (1985) also demonstrated coarticulatory effects on the schwa using electropalatographic data. In another study, Recasens (1989), using acoustic and electropalatographic data, indicated that the anticipatory effects of V_3 on preceding segments in /$V_1C\partial CV_3$/ utterances (i.e. V_1= vowel, $C\partial C$ = consonant- schwa - consonant and V_3 = another vowel) increase along the temporal domain as the degree of gestural antagonism for the preceding consonants decreases (/ʃ/>/t/>/p/). In other words, anticipatory effects for an upcoming segment are affected by the degree of dorsopalatal constriction in the adjacent segments.

Moreover, as shown by some recent crosslinguistic studies in normal established speech the characteristics of dynamic movement of the speech apparatus are not independent of vowel structure (Manuel and Krakow, 1984; Boyce 1990). Manuel and Krakow (1984) looked at two African languages which have a vowel system that differed from English. Their findings indicated that languages that have a reduced vowel system (five vowels), and, therefore, a wider distribution between vowel categories, exhibited significantly greater anticipatory coarticulation than English. This coarticulation crossed the consonant/syllable boundary. Both F1 and F2 center values of a particular vowel showed considerable variation depending on the following vowel in Swahili and Shona but not in English.

As Manuel & Krakow point out, the number of vowels in a vowel system may not always be concomitant to the width of vowel distribution. Parameters such as the size of vowel target areas (token-to-token variability within a vowel) and their distribution in the vowel space may independently affect the extent of anticipatory coarticulation on other languages. On comparisons of vowel area size in three languages that differ in the number of vowels, i.e. German, English and Greek, Jongman, Fourakis & Sereno, (1989) have found no relationship between the two variables. More crosslinguistic studies are needed to further explore the dynamic manifestations of vowel structure in speech.

Apart from the segmental constraints that characterize coarticulation phenomena (e.g. temporal extent of articulatory gestures, occurrence of articulatory conflict), the impact of suprasegmental aspects, such as stress and speaking rate, have also been assessed by a number of studies (Harris, 1971, 1973, 1978; Sussman and MacNeilage, 1978; Gay, 1974, 1978, 1981; Gay, Ushijima, Hirose & Cooper, 1974; Verbugge & Shankweiler, 1977; Tuller, Kelso & Harris, 1982; Bell-Berti & Krakow, 1991). On the effects of speaking rate, Bell-Berti & Krakow (1991) in a movement study have shown that gestural overlap between two neighboring segments increases with increases in speaking rate. Their data indicated that two distinct velic lowering movements ascribed to the production of neighboring /a/ and /n/ in the nonsense word /lansal/ at normal rate merge into one velic movement when the same utterance is produced at fast rates.

Regarding the effect of speaking rate on vowel formants, early studies yielded conflicting findings (Gay et al., 1974; Gay, 1974; Gay, 1978; Gay, 1981). In the Gay et al. (1974) article, the vowel productions (/i/, /u/, /a/) in /kV_1CV_2p∂/ utterances (C= /p/ or /w/, V_1 = first vowel type, V_2 = second vowel type and /∂/ = schwa) were assessed via simultaneous recordings of EMG and cinefluorography data. In their EMG data, the activity levels of the genioglossus muscle decreased at fast rate. The magnitude of the decrease was greatest for /i/, less for /u/, none for /a/. This finding was mirrored in their cinefluorography data (high speed X-ray films) with a reduction in the displacement of vowels (i.e. undershoot). The above changes occurred for both V_1 and V_2.

In the Gay (1974) article, cinefluorographic data (VCV frame; C= /p/, /t/, /k/ and V= vowel /i/ or /u/ or /a/) revealed a trend for a decrease in articulatory displacement for vowels /i/, /u/, /a/ in a number of instances, although adequate target vowel positions were attained. Acoustic analysis of F1 and F2 did not reveal systematic effects of undershoot (neutralization). Increases in speaking rate were accompanied by increased formant frequencies (F1 and F2) for point vowels. Harris (1978) also reported formant frequency changes with increased speaking rate that could not be accounted for by neutralization or contextual assimilation.

However, acoustic studies by Verbugge & Shankweiler (1977) and Gay (1978), contradicted the above findings by showing no change in the midpoint formant frequencies of vowels as a function of rate. In Gay (1978), the main utterance set comprised nine vowels in a /p_p/ environment. Most importantly, the difference between the second formant frequencies at normal vs. fast rates occurred at vowel onset where, at fast rate, the onset frequency was closer to the target frequency. A calculation of F2 transition rate -- i.e. the difference between the F2 midpoint and F2 onset divided by the transition duration -- revealed no differences as a function of rate. Thus, increased gestural overlap was inferred. In Gay (1981), physiological data provided support for increased consonant-vowel gestural overlap at fast rates. In /∂pip∂/ utterances (where /∂/ = schwa), acoustic recordings and simultaneous EMG recordings of orbicularis oris (OO; lips) and genioglossus (GG; tongue) muscles indicated that, at fast rate, genioglossus activity begins 50 msec earlier relative to the consonant release shown on the waveform. In other words, the onsets of OO and GG activity occurred within a shorter temporal interval at fast rate.

It appears that a great degree of variation exists in how different speakers enact the overlapping sequence of articulatory maneuvers at fast speaking rate. Tuller, Kelso and Harris (1982) conducted a systematic EMG study on the effects of stress and speaking rate on consonant and vowel articulation in a broad set of muscles, using linguistically naïve speakers (Experiment 2 of the study). The speech utterances were of /pV_1pV_2p/ type, where vowel context included all four combinations of /i/ and /a/. Stress varied orthogonally with speaking rate by placing emphasis on the first and second syllable alternatively. Results revealed that: a) EMG manifestations of stress variation were uniform for vowel-related muscle activity, i.e. decreased EMG peak amplitude and EMG duration for lesser syllables (more variation was noted for consonant-related muscle activity); b) EMG manifestations of rate variation were less consistent for vowel-related muscle activity across muscles and subjects. Types of variation with increased rate, consistent for vowel-related muscle activity, consisted of decreased duration of muscle activity and no changes in EMG peak amplitude, or, increased EMG peak amplitude and no changes in duration of muscle activity, or, decreased duration of muscle activity and increased EMG peak amplitude.

In sum, a coherent account of coarticulation as a function of segmental and suprasegmental variation exists in the literature for normal speech production. We will now turn to findings of speech motor characteristics of individuals who have acquired speech through modalities other than hearing alone. At this point, it is important to mention a few difficulties encountered in the body of literature for this population which relate to nomenclature and classification:

a) Some studies have not used strict audiological criteria for subject selection, i.e. included subjects with a wide range of hearing losses (e.g. Angelocci et al.1964; Monsen 1976)[1].

b) Studies have used a variety of terms, such as "severely-profoundly hearing-impaired", "severely-profoundly deaf", "profoundly hearing-impaired", "profoundly deaf", "deaf", "persons with a profound hearing impairment", to refer to persons whose hearing losses are above 90 dB HL. This variety of terms arises partly from the fact that some authors place a boundary between profound and severe loss at 90 dB HL hearing loss (Boothroyd, 1982; Silman & Silverman, 1991), while others place this boundary at 91 dB HL hearing loss (Jamieson 1994).

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[1] It is possible, though, that in the old studies the speech of subjects with severe (above 60 dB HL) and profound hearing losses (above 90 dB HL) was similarly impaired due to the limited benefit from the existing hearing aid technology at that time and the limited use of hearing aid amplification

c) Although it is most common that persons with hearing losses above 90 or 91 dB are classified within a single category, i.e. "profound hearing loss", their speech perception capacity, as measured by speech pattern contrasts, varies greatly depending on their actual hearing loss (Boothroyd, 1984).

In order to avoid confusion, in contrast with previous studies, this study employed a stricter audiological criterion (PTA > 105 dB in the better ear) for subject selection in hope of obtaining a more uniform sample of talkers. For the sake of simplicity of reference, it was decided to use the generic term "deaf" to refer to all the subjects in the studies reviewed below as well as in the present study. All subjects in the present study were orally trained and had sustained prelingual hearing losses whose magnitude did not enable them to acquire speech by hearing alone. On the other hand, consideration of the above mentioned difficulties in both nomenclature and classification will be made. Information on the subjects' PTA level in the better ear will be provided, whenever possible, for each of the studies.

Very few studies have investigated the issue of coarticulation in the speech of deaf individuals. Traditional investigations in the speech of deaf individuals have been primarily concerned with description of static articulatory error patterns (segmental errors). Hence, questions centered on target accuracy and target differentiation compared to the norm.

With respect to static aspects of consonant articulation, Huntington, Harris and Sholes (1968) studied the articulations of several consonants (/p/, /b/, /m/, /w/, /f/, /t/, /s/, /ʃ/, /r/, /l// and /k/) using surface electromyography on facial (upper lip, corner lip, lower lip) and tongue musculature (tongue tip, mid tongue and back tongue). They found that: a) deaf speakers[2] in their study exhibited internal consistency within consonant class in their productions and b) the topology of consonant productions generally resembled the normal pattern for more visible articulators (upper lip) and was idiosyncratic for less visible ones (tongue). This latter finding was derived from intrarticulatory comparisons of EMG activity between deaf and hearing speakers. Most interestingly, the two deaf speakers in this study performed similarly in their intrarticulatory correlations to the norm. Nevertheless, listeners distinguished the two deaf speakers from normals based on the intelligibility of their consonant productions.

With respect to static aspects of vowel targets, two theoretical positions have been advanced: a) Angelocci's "absent target hypothesis" indicating that vowels were not adequately differentiated (Angelocci, Kopp & Holbrook, 1964)

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[2] PTA= 89.3 dB HL in the better ear for the first deaf speaker. PTA ≥ 108 dB HL in the better ear for the second deaf speaker (note: no response at 2000 Hz within the limits of the audiometer.

and b) Monsen's (1974, 1976a) "deviant phonology hypothesis" indicating that vowels are adequately differentiated along a set of acoustic dimensions that is different from normal.

Rubin (1984) challenged the commonly held notion of deviancy of phonological vowel targets by examining the token-to-token variability of vowel targets spoken by deaf adolescents[3]. Rubin's study indicated that there is much variability in the production of vowels by deaf speakers. The vowel systems of deaf speakers depended upon the extent and direction of such variability. Three groups of deaf speakers were identified: a group with point vowel differentiation, a group with front/back differentiation of the vowel space only and a group with no differentiation of the vowel space (complete overlap). The extent of vowel differentiation in the vowel space paralleled intelligibility measures. The least intelligible group exhibited the greatest amount of variability (according to standard deviation measures), a finding that appears to contrast with the previously advanced notion of "reduced lingual mobility" (Angelocci et al., 1964; Monsen 1976a). Angelocci's and Monsen's observations can also be explained by the concept of variability in the acoustic vowel space. In Figure 1.1, one might

[3] PTAs in dB HL in the better ear for each of six subjects: D1= 107, D2=88, D3= 95, D4= 85, D5= 93 and D6=105.

conclude based on F2 averages that there is no differentiation of vowels along F2. This assumption is consistent with Monsen's account, where deaf talkers differentiate vowels along F1 but not F2. However, based on token analysis, the hypothetical example plotted above suggests that some tokens of different vowel categories are differentiated along F2 while others are not, a conclusion drawn from Rubin's variability hypothesis.

In Figure 1.2, one might conclude based on formant averages that F1 and F2 values do not change across vowel categories, therefore infer "reduced lingual mobility" across all productions. This inference is not valid when the above hypothetical example is examined based on token analysis. One may observe that a considerable amount of tongue front/back movement is inferred based on F2 variation and that certain tokens are differentiated across vowel categories. This view is consistent with Rubin's variability hypothesis.

Although such token-to-token variability, within each vowel, was confirmed in a case study of a prelingually deaf speaker[4] conducted by McGarr & Gelfer (1983) using acoustic analysis, EMG measurements in the same study indicated undifferentiated activity of the genioglossus (GG) muscle across perceptually

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[4] PTA in the better ear was 105 dB HL.

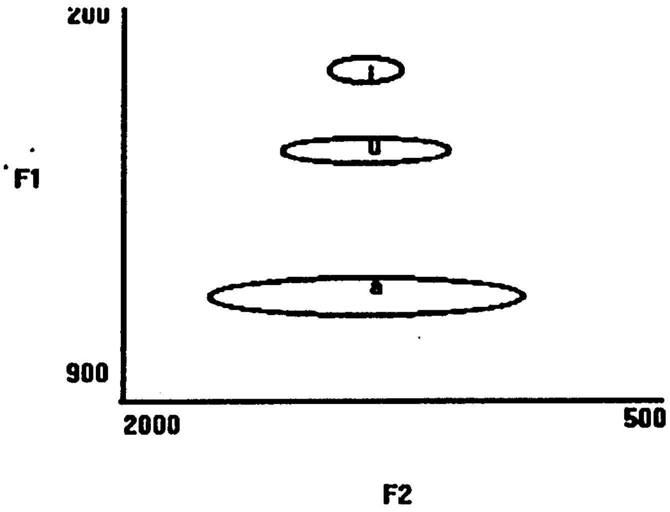

Fig. 1.1: Alternative explanation of Monsen's "deviant phonology" hypothesis. This is a theoretical illustration of token productions of vowels by a deaf speaker plotted in a F1/F2 hypothetical vowel space. Vowel categories have partial overlap along the F2 acoustic dimension and no overlap along the F1 dimension.

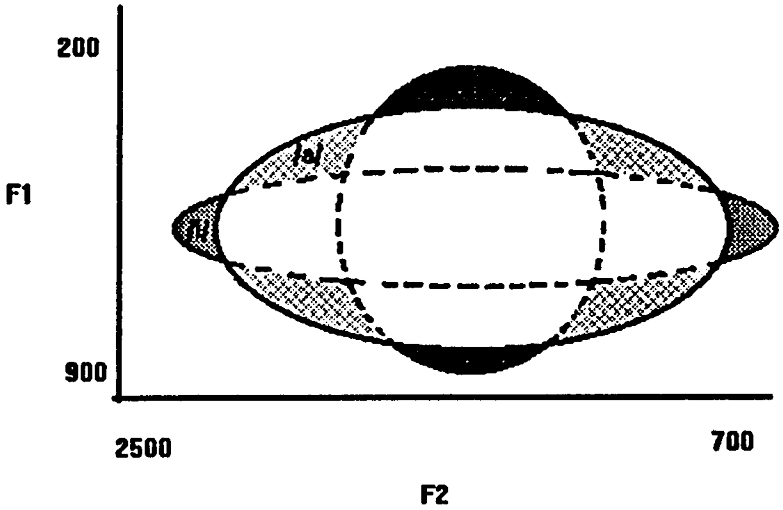

Fig. 1.2: Alternative explanation for Angelocci's "absent target" hypothesis. This is a theoretical illustration of token productions of vowels by a deaf speaker plotted in a F1/F2 hypothetical vowel space. There is a considerable overlap between vowel categories along both the F1 or the F2 acoustic dimensions.

correct and incorrect vowel targets. This apparent discrepancy between acoustic and physiological findings is subject to two possible interpretations: 1) There was differentiated lingual movement, as indicated by the variable acoustic targets but EMG measurements were only conducted for GG muscle and not for other lingual muscles that might have been responsible for movement. 2) There was reduced, undifferentiated lingual movement, as inferred by the EMG data but acoustic analysis showed increased variability in the vowel center formant values due to different degrees of coarticulatory overlap at each /h_d/ token production -- induced by durational variation.

Regardless of the ambiguous above-mentioned articulatory underpinnings of vowel target variability, the above study indicated that inconsistencies in the temporal relationship between the offsets and onsets of orbicularis oris muscle and genioglossus muscle activity, respectively, were perceptually relevant, leading to equivocal or incorrect identification of the vowel target /u/ as /y/. A similar finding was reached by Calvert (1962) who investigated the perceptual consequences of the speech of deaf individuals[5]. He found that presentation of static articulatory events alone (gated vowel targets) failed to allow listeners to distinguish the speech of deaf from hearing individuals. Perceptual identification of the speech

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[5] The information on PTA was not found.

patterns of deaf individuals was satisfactory only on presentation of dynamic articulatory movement, i.e. a CVC. Considering the above, it is inferred that aberrant dynamic movement may underlie the discriminable qualities of the speech of deaf talkers.

A few physiological studies have examined the coarticulatory patterns of deaf speakers with respect to both intra- and interarticulatory timing in running speech. They reported either decreased or increased or variable coarticulation for deaf talkers depending on the dimension studied (duration of articulator movement, intrarticulator overlap, interarticulator overlap).

A kinematic study by McGarr, Lövqvist and Story (in press) found evidence on the breakdown of articulator timing which exists even for visible articulators such as the jaw. Movement duration, velocity and displacement of the jaw were examined in short phrases (e.g. "Bea pops it", "Pa peels it") spoken by three deaf female speakers[6] and a hearing female speaker. Deaf speakers generally exhibited normal-like production patterns with respect to movement displacement for /i/ vs. /a/ positions, movement duration, inter-token variability and movement velocity of jaw-raising and jaw-lowering gestures. However, the duration of the "hold phase", i.e. the interval between jaw-raising and jaw-lowering gestures

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[6] PTA was 90+ dB ISO in the better ear

where the jaw was kept in a stable position, in the vowel productions of deaf speakers did not vary systematically with vowel context and stress, as it did for the hearing speaker. The absence of differences between hearing and deaf talkers in movement duration and movement velocity of the jaw indicates that the slower speaking rate in deaf compared to hearing talkers is not attributable to movement but more likely stems from durational differences in the "hold phase".

An electropalatographic of voiceless sibilant productions, where both consonant and vowel gestures were uttered by the tongue, showed evidence of increased coarticulation for some of the deaf adult speakers[7] study (McGarr, Raphael, Kollia, Kaloustian & Harris, 1991). That is, there was a temporal delay for release of contact patterns occurring subsequently to the onset of voicing for the following vowel.

With respect to the temporal coordination of different articulators, physiological studies have indicated inconsistencies in coarticulatory and voicing patterns of deaf speakers, i.e. a breakdown in interarticulator timing (McGarr & Harris 1983; McGarr & Löfqvist 1982). McGarr & Harris made EMG

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[7] PTA was not reported.

measurements of orbicularis (OO) and genioglossus (GG) muscle activity during production of /papip/ utterances with alternating stress (/'papip/ vs /pa'pip/) by deaf speakers[8]. Poor lingual control, evidenced in the great token-to-token variability in GG onset peak, revealed difficulties in the coordination of muscle activity across articulators. The onset of GG muscle activity occurred either later or earlier than the OO muscle activity and sometimes continued beyond the onset of OO muscle activity for the final /p/. The magnitude -- but not the direction -- of discoordination between the two muscle activities was perceptually relevant. Tokens where the GG muscle activity occurred either too early or too late compared to the OO muscle activity were identified as incorrect. The duration of peak activity was more variable and, in general, prolonged for both muscles. Stress patterns were similar to those of hearing speakers but with distinctly greater variability. Thus, although the appropriate articulatory mechanisms were employed for generation of the utterances, the variability in the execution of articulatory movements clearly had a negative impact on intelligibility.

McGarr and Lövqvist (1982), using transillumination and electrical transconductance techniques to observe glottal and supraglottal pattern

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[8] PTA in the better ear was 105 dB HL.

respectively, demonstrated that a similar interarticulatory breakdown occurs in the coordination of upper articulatory and laryngeal gestures. Using several types of stimuli that were contrastive along the voicing dimension, i.e. stops, fricatives, affricates and fricative-stop clusters (e.g. /st/) they measured two intervals in interarticulator timing: a) the interval between closure onset and peak glottal opening and b) the interval between peak glottal opening and release. Their findings indicated that the deaf speakers[9] in the study exhibited highly variable patterns, both within and across subjects. The hearing-impaired speakers generally failed to produce the voiced/voiceless distinction in a consistent way that resembled the hearing speakers' patterns. They either a) made a glottal abduction/adduction gesture when none was required (e.g. prior to the onset of oral closure for stops, during pauses between words; during the production of a voiced stop; during the production of a voiced fricative), b) failed to produce one (e.g. during the production of voiceless stops) or c) correctly produced one but sometimes failed to coordinate it with supraglottal events (e.g. for production of the /st/ cluster, peak glottal opening occurred after the oral release, as in the production of an aspirated stop).

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[9] PTA in the better ear was 90+ ISO.

A few acoustic studies have also been conducted on coarticulation by deaf individuals. They have uniformly reported decreased coarticulation in the speech of deaf talkers as compared to the hearing controls. However, although the focus in physiological studies has been the analysis and interpretation of token data and within-subject patterns, acoustic studies derived their findings from averaged data, within and across deaf speakers.

Monsen (1976b)[10] and Rothman (1976)[11] described the second formant transitions in the speech of deaf adolescents as flatter and shorter than normals. Although they claimed that this finding was evidence of reduced coarticulation, two other explanations can be advanced: a) The formant transitions were shorter and flatter because most of the anticipatory lingual movement of the vowel gesture occurred during the consonant closure of the CV sequence. b) The vowel space (articulatory targets) produced by deaf speakers was more collapsed and neutralized than the vowel space of normally-hearing controls, thus, formant

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[10] PTAs in dB HL in the better ear: D1= 65.6, D2= 82.3, D3=88.9, D4=97.3, D5=100.6 & D6=103.9.

[11] PTAs in the better ear greater than 110 dB HL.

transitions were shorter and flatter. In addition, the methodology in both studies contained several flaws. In the Monsen study, subject selection was inappropriate for two reasons: i) deaf subjects were adolescents, ages 13-15, making detection of formants in their speech difficult because of widely spaced harmonics (a result of high Fo) and other phonatory problems related to voice changes during puberty; ii) a diverse hearing-impaired sample was used, that is, hearing loss ranged from severe to profound; iii) choice of stimuli consisted of a mixture of open and closed syllables; iv) F2 values were measured over an absolute interval (120 msec) regardless of each speaker's segment durations; v) intelligibility data were absent. In the Rothman study i) findings were solely based on average data across groups, normally-hearing vs. deaf ii) Rothman selectively examined data by eliminating perceptually deviant tokens from the deaf sample to reduce intertoken variability iii) he did not examine differences in duration of segments among groups iv) he did not balance stimulus context in terms of consonantal place of articulation (three alveolar vs. one velar/palatal position), and did not analyze places of articulation separately (i.e. the effect of an alveolar vs. a velar consonant on the preceding schwa).

Two recent studies used acoustic analysis to examine the effects of anticipatory and carryover coarticulation in the speech of deaf children[12] (Baum & Waldstein 1991, and Waldstein & Baum 1991). Centroids and F2 vowel onset and vowel offset measurements were made for fricative and stop CV and VC syllables. Coarticulatory magnitude was measured by comparing ratios of Ci/Cu (Ci = consonant + /i/; Cu = consonant + /u/) for centroids and F2 values. Both of those studies indicated that intelligible, deaf children exhibit both anticipatory and carryover coarticulation but to a lesser extent than hearing children. Anticipatory coarticulation was significantly less than that of hearing speakers and carryover coarticulation was either comparable or slightly less than that of hearing speakers. These experimental findings, however, were confounded by assumptions about the normality of vowel targets. The average F2 values for /i/ and /u/ were less differentiated in the speech of deaf children than in their hearing counterparts.

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[12] PTA levels in dB HL in the better ear: D1=100, D2= 100, D3=90, D4= 105, D5= 100, D6= 93, D7=90, D8= 102,D9 >105 (no response at 2000 Hz).

A cinefluorographic study on deaf speakers[13] provides support for the findings reported in acoustical studies, that is, reduced coarticulatory patterns for the less intelligible deaf speakers (Tye-Murray 1987). In this study, Stein's (1980) data were used to examine perturbations of jaw and tongue closure postures with vowel context and a separate analysis was done for each subject Deaf subjects exhibited reduced coarticulatory patterns by failing to assume anticipatory lingual, jaw and/or lip-rounding configurations during dorsal and/or bilabial closures respectively, corresponding to the upcoming vowels /i/, /u/ and /a/. The degree of intelligibility paralleled the degree of coarticulatory behavior in that the more intelligible deaf speakers produced a greater span of coarticulatory patterns.

[13] PTA levels in dB HL in the better ear: D1= 90, D2= NR, D3= 95, D4= 97, D5= 95.

METHOD

2.1 SUBJECTS

Two groups of adult subjects were used: Three subjects with normal hearing and three subjects with a profound hearing loss. All were adults, monolingual speakers of English. The hearing subjects spoke dialects typical of the Northeastern United States. Table 2.1 provides information on each subject's age, sex, hearing status and etiology.

The hearing subjects were members of university communities who had lived in the Northeastern region of the U.S. since their childhood. Before this study, an audiological screening at frequencies 500 Hz, 1000 Hz, and 4000 Hz, was performed in a sound-treated room using a GSI audiometer (Model 10). All three subjects had normal hearing, i.e. their hearing thresholds were below 15 dB HL at each of the three audiometric frequencies. No subjects reported past or present incidence of motoric or neurological handicaps.

For all three deaf subjects, an audiological history of cause, severity and stability of hearing loss obtained from their school records indicated a bilateral prelingual profound hearing loss, possibly since birth. The cause of hearing loss was either unknown or thought to be genetic (see Table 2.1). They all spent several years of their education in oral/aural schools for the deaf in the Northeastern United States: Subject D1 attended the Preschool for the Deaf at the

University of Kansas Medical Center and then the Clarke School for the Deaf in Northampton, MA until the eighth grade. He was then mainstreamed into a public school. Subject D2 attended the Lexington School for the Deaf in New York, NY throughout her elementary and high school years. Subject D3 attended Clarke School for the Deaf for three and one-half years and then attended a private regular school.

The deaf subjects had undergone a complete audiological evaluation within twenty-four months of this study. The audiological evaluation included air conduction testing at 250, 500, 1k, 2k, 4k and 8k Hz, bone conduction testing, speech discrimination testing using the AB or NU6 word lists and tympanometry. Audiological testing was conducted by a certified staff audiologist at an oral/aural school. The audiological scores for each deaf subject are provided in Table 2.2. As seen in Table 2.2, the deaf subjects had three-frequency average thresholds of 107, 107, and 110 dB HL in the better ear. The speech discrimination scores were obtained from either AB or NU6 word lists.

Table 2.1: Age, sex and hearing status and etiology of hearing loss of talkers.

H: hearing subject; D: Deaf subject.

Subjects	Age	Sex	Hearing Status	Etiology
H1	26	Male	Normal	N/A
H2	41	Male	Normal	N/A
H3	29	Male	Normal	N/A
D1	39	Male	Profound hearing loss	possibly genetic
D2	54	Female	Profound hearing loss	unknown
D3	61	Male	Profound hearing loss	unknown

TABLE 2.2: Audiological information on talkers with profound hearing loss

Talker	Better Ear PTA dB HL	Better Ear Speech Detection thresholds, in DB HL	Better Ear Most Comfortable Listening Level (MCL), in dB HL	Speech Discrimination Scores % of words recognized
D1	107	80	100	13% (AB word lists)
D2	107	90	105	<10 % (NU-6 lists)
D3	110	90	105	<10 % (NU-6 lists)

It should be noted that the three deaf subjects in this study have some common characteristics beside the ones specified in their category classification (i.e. profound hearing loss). These common characteristics are: a) prelingual onset of hearing loss, b) a PTA greater than 103 dB HL, c) an aural/oral education, d) self-reference as "deaf". For these reasons, but primarily for the sake of simplicity of reference, these subjects in this study will be referred to as "deaf talkers". The subjects with normal hearing in this study will be referred to as "hearing talkers".

The deaf speakers in this study had previously participated in a speech intelligibility study by McGarr & Campbell (1995). In the McGarr & Campbell study, Boothroyd's (1984, 1985) isophonemic word lists (the AB word lists) were used as the speech intelligibility measure because they provide speech intelligibility scores that are relatively independent of listener experience and predictive of a person's speech intelligibility in natural settings. Each of Boothroyd's isophonemic word lists is phonemically balanced, i.e. it contains ten CVC words where consonant-vowel combinations vary to encompass a total of thirty English phonemes. This speech intelligibility test is an open-set recognition task of phonemes in monosyllabic words in the carrier phrase "Write the word __ next".

McGarr & Campbell combined eight of Boothroyd's fifteen lists into four lists of twenty words each. Each deaf person was asked to produce two of the four lists. The sentences were digitized, and re-recorded onto listening tapes in random order. Randomizations were made within list and across talkers, so that each listening tape presented one list from each of the twelve speakers. For each of the deaf talkers in the present study, McGarr & Campbell report an average percent score from fifteen listeners for the recognition of words, consonants and vowels (see Table 2.3). Talker D1 has higher speech intelligibility scores than talkers D2 and D3 in each of the three categories: words, consonants and vowels.

Table 2.3: Speech intelligibility scores from McGarr & Campbell (1995):

Talker	% Words Correctly Understood by Listeners	% Consonants Correctly Understood by Listeners	% Vowels Correctly Understood by Listeners
D1	46%	68%	68%
D2	23%	57%	42%
D3	16%	42%	31%

2.2. MATERIALS

Two types of speech materials were used: a) vowels embedded in a CVC nonsense syllables within a carrier phrase and b) isolated sustained vowels. An orthographic code was used for presentation of all speech materials. This orthographic code is used in schools for the Deaf of the Northeastern region of the U.S. to teach pronunciation of vowels to deaf students.

The speakers read CVC nonsense syllables embedded in the carrier phrase "a ___ again". Two symmetrical consonant contexts were used: /b_b/ (to assess intergestural overlap when consonants and vowels are formed by independent articulatory systems) and /d_d/ (to assess intergestural overlap when consonants and vowels are formed by the same articulatory system, i.e. the tongue). The embedded vowels were the three point vowels /i/, /a/, /u/. These were chosen in order to allow inferences about both lingual fronting/backing as well as about lingual height and lip/jaw behavior. The isolated, sustained vowels /i/, /a/, /u/ were also produced by the subjects. These vowels were identified for the speakers in the context of monosyllabic words, presented without a carrier phrase.

Ten repetitions of each isolated vowel and each CVC utterance type were produced by each speaker. The utterance types were presented at two speaking rates, "normal" and "fast". A total of 150 tokens was analyzed per speaker, (3x2x2x10=120 utterances, 3x10=30 vowels in sustained production). The total number of analyzed tokens for all subjects was 900.

The utterance types were presented in randomized order. The rate conditions were presented alternately in block trials, i.e. normal, fast, normal, fast. Each block consisted of thirty utterances. Tables 2.4 and 2.5 summarize the randomized lists of speech materials.

An additional set of speech materials was used for deaf talkers only, during a second day of recording. It consisted of ten English vowels embedded in words in a /h-d/ frame. This recording was made in order to sample the vowel space of the deaf talkers in this study. Ten tokens containing the same vowel were produced in randomized lists (Table 2.6). Normative data were not sampled because information about the vowel spaces of hearing talkers is available in the literature (Peterson and Barney 1952).

Table 2.4: Randomized lists of monosyllabic words used to cue production of isolated, sustained vowels.

List #1	List #2	List #3
hot	seed	seed
flute	flute	hot
seed	seed	seed
hot	hot	flute
seed	flute	hot
flute	hot	flute
seed	seed	seed
flute	flute	seed
hot	flute	flute
hot	hot	hot

Table 2.5: Randomized lists of the CVC nonsense words that subjects produced in a carrier phrase.

Section 1 Normal rate	Section 2 Fast rate	Section 3 Normal rate	Section 4 Fast rate
beeb	beeb	bob	bob
dude	dude	deed	deed
bob	bob	bube	bube
deed	deed	dod	dod
bube	bube	dude	dude
dod	dod	beeb	beeb
deed	deed	deed	deed
beeb	beeb	dude	dude
dude	dude	bube	bube
dod	dod	bob	bob
bob	bob	beeb	beeb
bube	bube	dod	dod
bob	bob	bube	bube
dude	dude	deed	deed
beeb	beeb	bob	bob
dod	dod	beeb	beeb
bube	bube	dod	dod
deed	deed	dude	dude
bob	dod	dod	dod
dod	bob	beeb	beeb
bube	bube	dude	dude
beeb	beeb	bob	bob
deed	deed	deed	deed
dude	dude	bube	bube
bube	bube	beeb	beeb
dude	dude	dude	dude
deed	deed	bube	bube
dod	dod	bob	bob
beeb	beeb	dod	dod
bob	bob	deed	deed

Table 2.6: Randomized lists of h_v words used for sampling the vowel space of deaf talkers.

list #1	list #2	list #3	list #4	list #5	list #6	list #7	list #8	list #9	list #10
had	heed	hid	hawed	hood	hud	heed	hawed	hawed	had
hawed	head	had	hid	hud	head	hawed	heed	had	hawed
heard	hid	whod	heard	heard	hawed	hud	had	hood	heed
whod	whod	hawed	hud	hawed	heed	hid	hod	heed	hod
hid	hawed	hood	head	hod	hid	head	head	heard	heard
hud	hud	heard	hod	had	hod	whod	hood	head	hid
hood	had	hod	hood	heed	had	hood	heard	hod	hud
head	heard	head	had	head	hood	hod	hud	whod	whod
hod	hood	heed	heed	whod	whod	heard	whod	hud	heed
heed	hod	hud	whod	hid	heard	had	hid	hid	head

2.3 EQUIPMENT AND RECORDING PROCEDURE

Speakers were recorded using a Panasonic digital tape recorder (Model SV-255) and a Shure (Model SM-10) head-band unidirectional microphone. A Radio Shack mini-microphone was placed under the subject's nostrils to sample the nasal acoustic ouput. Adhesive tape was used to keep the mini microphone in a fixed position. A digital metronome with a flashing light was used to induce faster speaking rates. Hearing talkers were given a choice of the mode of the metronome, whether audible ticks or light flashes. Deaf talkers relied on the flashing light. Metronomic rate was set 25% faster than the subject's normal speaking rate (Gay. 1981; Tuller, Harris, and Kelso, 1982; Smith, Sugarman, and Long, 1983). Recordings were made in sound-attenuated rooms at the CUNY Graduate School and at the Clark School for the Deaf, for hearing and deaf subjects respectively.

Subjects were presented with a written draft of general description and instructions about their part of the experiment. Subsequently, they were familiarized with the orthographic representation of the speech material, i.e. the point vowels and the CVC nonsense words:

a) In familiarizing the subjects with the orthographic code for point vowels, three sets of words were used, each set containing one of the vowels [i], [u], [a]. The words used were: <u>seed</u>, <u>need</u>, <u>feed</u>, <u>flute</u>, <u>nude</u>, <u>lute</u>, <u>hot</u>, <u>box</u>, <u>top</u>. The experimenter produced each set of three words containing the same vowel, and then produced the vowel contained in each word in isolation. Subjects were asked to imitate this routine and then to read each word silently and speak only the vowel it contained.

b) In familiarizing subjects with the orthographic code for CVC nonsense words, the experimenter produced one token of each of six isolated CVC test stimuli types. Subjects were asked to utter each of the six CVC nonsense words after it was modeled by the experimenter.

Then the experimenter read aloud the first part of the instructions: "You are asked to utter this phrase at your comfortable rate as if you are carrying out an everyday conversation. Then, once you feel comfortable, we will begin the recording." The experimenter modeled a single utterance ("a beeb again") twice, at her normal rate. Subjects were subsequently asked to produce the same utterance, several times, at their normal rate, to allow for a metronomic reading at that rate. The metronomic reading was obtained by listening and manually adjusting the metronome (in beats per minute) to the subject's speaking rate. The recording of the first session began as soon as this trial period ended.

Following the recording of the first session, the experimenter increased the metronomic setting of each subject's conversational rate by 25%. She read aloud another set of instructions: "You are asked to utter this phrase faster, without leaving out parts of words or parts of the phrase. Pace yourself to the metronome during the trial period. Then, once you feel comfortable speaking faster, switch off the metronome and we will begin the recording." For demonstration purposes, the experimenter attempted to pace herself to the subject's metronomic fast rate. The recording of the second session began as soon as this trial period ended. The next two recording sessions proceeded with brief instructions only.

Subjects were asked to read every token once. Repetition was permitted under the following conditions: a) the subjects corrected themselves, b) consonantal closure was not observed in initial and/or final position. To facilitate the rate task a) stimuli were printed in large vs. small print for normal and fast speaking rates, respectively and b) the experimenter flipped the pages containing the stimuli sets at a faster or slower rate, depending on the experimental condition. Subjects were cautioned to speak only after the page was flipped. During all four recording sessions, the subject's rate was checked by a brief session of looking at light flashes at the appropriate setting.

During a second day of recording, the deaf subjects were asked to utter ten English vowels embedded in words with an h_d frame (Table 2.6).

2.4 DATA ANALYSIS

Utterances were played back from a digital recorder (Sony DAT Walkman, model # TCD-D7) and digitized at 12500 samples per second using "WAVEXAM", a speech editing and analysis program designed for microcomputer by M. Weiss of the Ph.D. Program in Speech and Hearing Sciences at CUNY. Each utterance was edited by deleting periods of silence greater than 30-45 msec prior to the first schwa onset and the portion of the waveform following the offset of periodic activity of the second schwa (in “again”). The remaining portions of each utterance, i.e. 25-40 msec before the onset of the first schwa until the offset of periodic activity of the second schwa, were kept in a digital file which was subsequently used for durational and spectral measurements. The durational measurements were made by using the "WAVEXAM" program. The spectral measurements were made by importing each digital file to the Kay Elemetrics Computerized Speech Lab (CSL) using the same sampling rate.

2.4.1. Measurement of durations

Six measurements were made of the durations of the different portions of the utterance: schwa, “closure”, Voice Onset Time (VOT)[14], vowel, CVC

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[14] Data on VOT and “closure” were not used in this study.

syllable and phrase. Figures 2.1 and 2.2 present an example of waveform segmentation for a hearing and deaf person respectively. Cursor placements were continuous, that is, the offset of a particular segment concurrently served as the onset of the following segment. A set of segmentation rules was used for delimiting the above utterance portions from the waveform as follows:

2.4.1.1. Schwa and stressed vowel segments.

The basic segmentation rule for the schwa and vowel segments was to place the left and right cursors at the onset and offset of complex periodic waveform activity, respectively. The schwa offset was defined as the point at which a) the amplitude of the periodic waveform decreased abruptly and b) it became sinusoidal. In addition, there were cases where the onset of the schwa was aperiodic, a pattern particularly exhibited by hearing talker H3. In these cases, an alternative segmentation rule was applied which involved inspection of the spectrographic record. If the formants in the aperiodic portion of the schwa were continuous with the rest of the segment, the aperiodic segment was included.

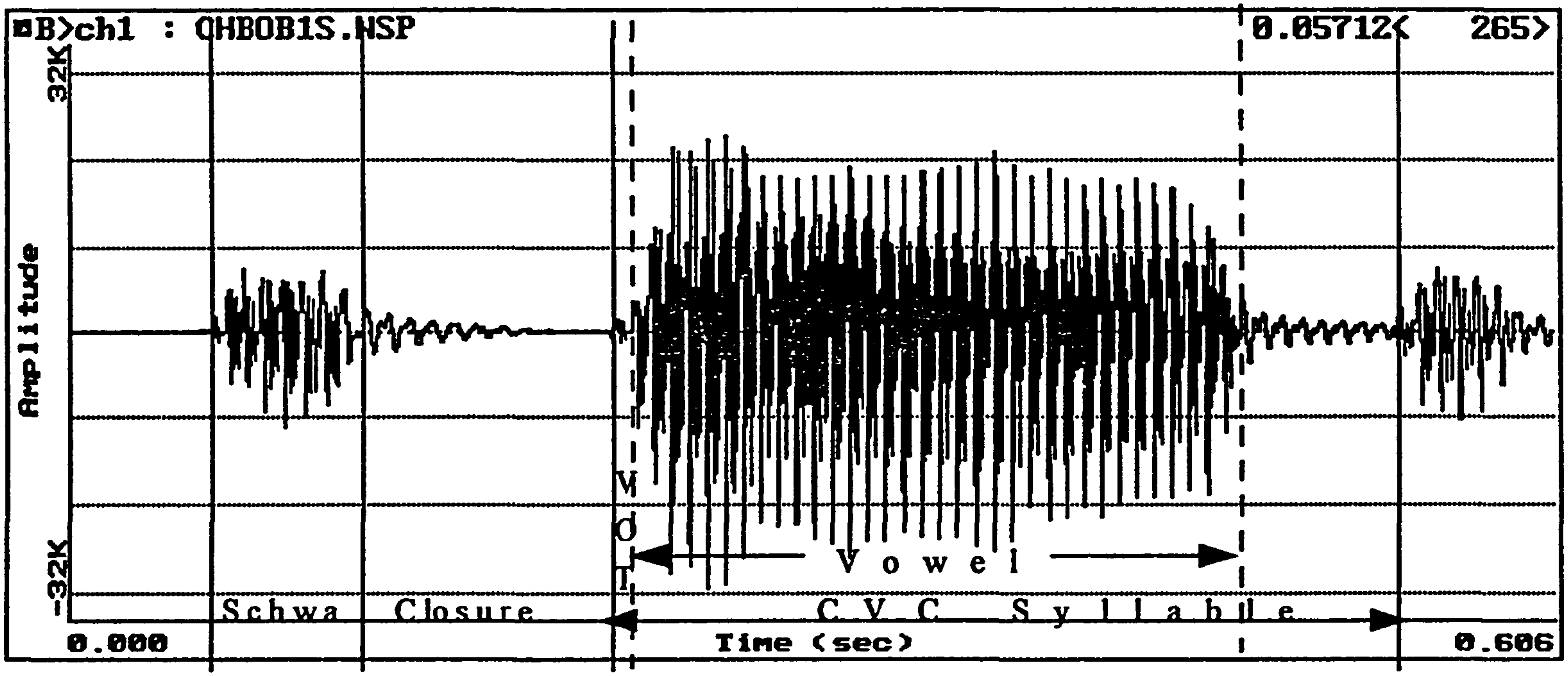

Figure 2.1: The utterance /∂bab/ produced by hearing talker H2.

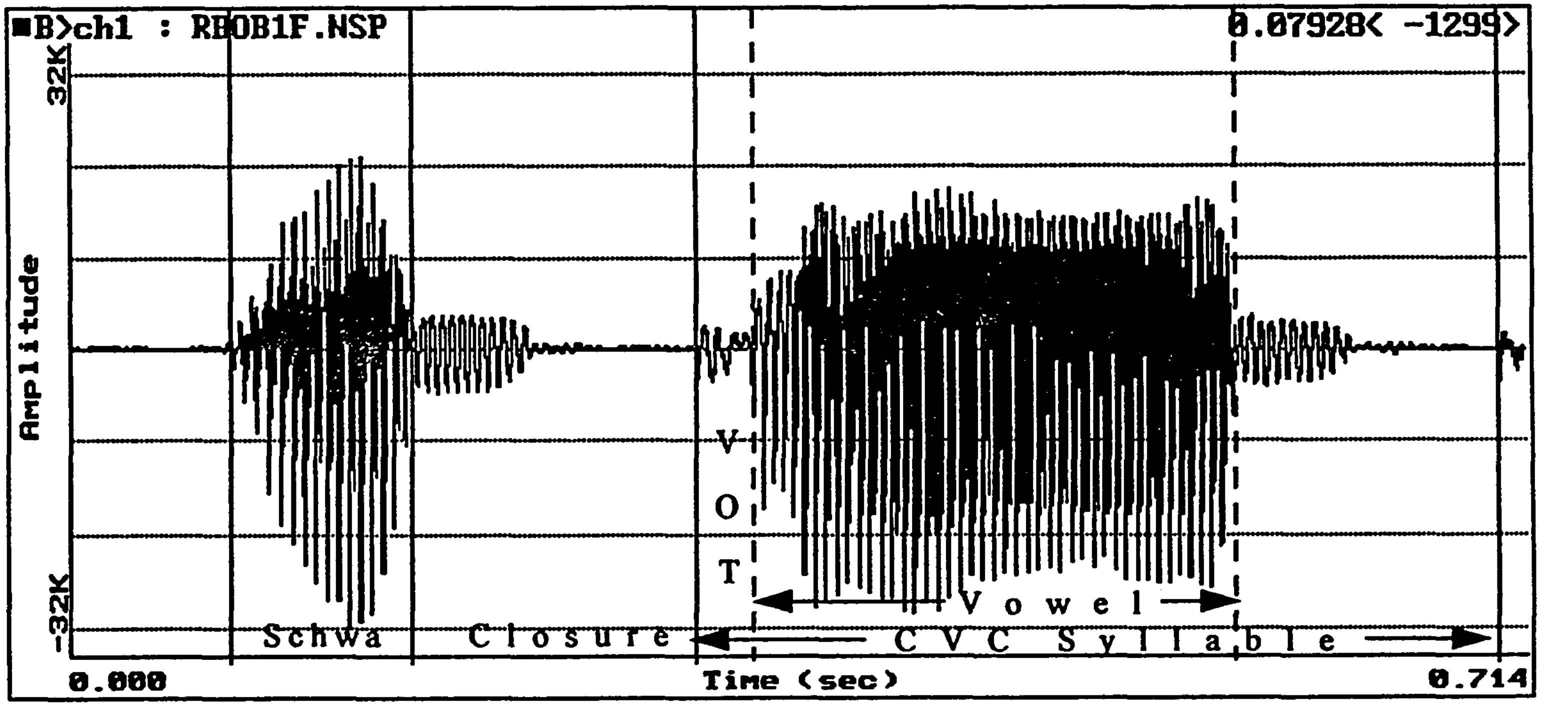

Figure 2.2: The utterance /ə̃bab/ produced by deaf talker D2.

2.4.1.2. Stop closure.

The stop closure boundaries were determined by placing the cursors between the schwa offset and the burst of the first consonant of the CVC syllable. Oftentimes, a low-amplitude periodicity was included at the early part of the closure interval. It was assumed that, for a brief time, subjects continued phonating after their vocal tract was closed. In less than 3% of the cases, in which the burst could not be readily identified, the onset of periodic activity of the stressed vowel was used as the right-hand boundary.

2.4.1.3. Voice Onset Time (VOT).

The VOT was measured from the burst of the first consonant of the CVC syllable to the onset of periodic activity of the stressed vowel. Since the stop consonants were voiced, VOT was oftentimes equal to zero, especially in the productions of hearing talkers.

2.4.1.4. Stressed syllable (CVC).

This interval was defined by placing the cursors at the bursts of the first and second consonants. The closure before the burst of the first consonant was not included because it was confounded with the intersyllabic pause. In 6% of the cases, mostly noted at fast rate, the burst of the second consonant was weak. In these cases a judgment of the stressed syllable interval was made by referring to the waveform display and listening to the acoustic signal. The cursor was placed at a location indicating a change of amplitude in the waveform display.

2.4.1.5. Phrase.

This portion began at the onset of phonation in the schwa and ended at the offset of phonation of the alveolar nasal in "again".

2.4.2. Measurement of formant frequencies

Frequency measurements were made by using the CSL. Measurements of F1 and F2 were made at five locations throughout the utterance: Schwa Onset (∂1), Schwa Midpoint (∂2), Schwa Offset (∂3), Transition Onset (Ton) and Stressed Vowel Midpoint (Vm). The Transition Onset is the point of the onset of the second formant.

As can be noticed, relative rather than absolute time (fixed values in milliseconds) was used for the selection of the above intervals in the acoustic signal. The rationale was that the amount of intersegmental overlap at a fixed temporal point is different in talkers with different segment durations. As known, there are consistent differences in the segment durations of hearing and deaf talkers (Osberger & Levitt, 1979; Osberger & McGarr, 1982) where the segments of the latter talkers are longer. In other words, in /∂CV(C)/ utterances the onset of the articulatory period for the upcoming vowel varies with speaking rate, thus measurement points should be determined based on relative rather than absolute time intervals.

In less than 1% of the cases, the durational midpoint of the vowel occurred before the F2 formant "peak" (e.g. the highest point for [i] or lowest point for [u] of the F2 trajectory). In these cases, the formant values recorded for vowel midpoint were those of the formant peak.

Fourier analysis was performed on the acoustic signal using a combination of wideband spectrographic and Discrete Fourier Transform (DFT) analysis in order to resolve spectral ambiguities. The spectrographic analysis was conducted using a 4.0 msec (i.e. 50 samples) Hamming window with high frequency preemphasis. The DFT analysis was conducted using primarily a 5.12 msec (i.e. 64 samples) Hamming window but oftentimes changing to more narrowband settings of 10.24 msec (i.e. 128 samples) when spectral peaks were not clearly resolved. Cursor placement was allowed to shift + or - 2 glottal cycles in order to obtain accurate measurement. The routine was to:

i) Obtain printouts of wideband spectrographic displays for a given talker for qualitative analysis, i.e. detection of possible formants (nasal and oral) and gross estimations of formant frequencies.

ii) Inspect all the tokens of an utterance type and speaking rate at once.

iii) A priori, set the temporal points where the spectral information would be sampled by placing cursors on the waveform display into positions that matched the durational values previously obtained for a given segment from the "WAVEXAM" analysis.

iv) Measure F2 in the middle of the selected energy band from the wideband display.

v) Measure F1 using a combination of wideband and DFT analysis.

The DFT enabled better measurement of the first formant (F1) than wideband spectrography when a) the F1 and F2 were not clearly separated (e.g. in /bab/), or b) there was nasality (weakness of F1 and nasal formants around 250-300 Hz), which would have resulted in underestimation of F1 if LPC or WB analysis were used.

The Wideband spectrography enabled better measurement of the second formant because a) the DFT estimate often shifted dramatically when cursors were moved by 2 glottal cycles to the left or right and b) The DFT display often had a "plateau" in the second formant (F2), making it impossible to specify the location of its peak value.

The spectrographic display obtained from the microphone placed under the nostrils was used selectively for identification of nasal formants.

Inter-observer reliability.

Eight utterances were randomly selected from CSL files for re-measurement by another observer using the same measurement protocol. Six utterances were taken from the speech of deaf talkers and two utterances were taken from the speech of hearing talkers. The inter-observer reliability for both F1 and F2 measures was estimated via r-correlations and is shown in Table 2.7 below.

It should be noted that the inter-observed reliability is weaker at schwa offset than it is at other measurement locations. The inter-observer values were examined for each token to see whether the relatively low reliability at schwa offset could be attributed to disagreement (a raw difference among formant ratings for a given token greater than 66 Hz) over a single token by the observers. This proved true for the first formant, but not for the second formant where there were several disagreements. Another possibility for the weaker inter-observer reliability at schwa offset is that the relatively low correlation might be due to a range effect in F2, i.e. the range of F2 values might be too small to render a valid correlation. However, the range of values at schwa onset (/∂1/) was very similar to the range of values at schwa offset (/∂3/). Namely for the first observer, an F2 range of 415 Hz was found at /∂1/ as opposed to 449 Hz at /∂3/ and, for the second observer, an F2 range of 294 Hz was found at /∂1/ as opposed to 242 Hz at /∂3/. Thus, it is concluded that the schwa offset was a particular difficult point to measure F2.

Table 2.7: Inter-observer reliability

	∂1	∂2	∂3	Ton	Vm
F1	.97	.93	.85	.81	.93
F2	.93	.90	.65	.98	.93

2.5 STATISTICAL DESIGN

Means and standard deviations were calculated for each of the measurement points of the disyllable and for each subject separately. Four types of analysis of variance were used. For Section 3.1 (see Results), a 3x3 two-way univariate analysis of variance was performed for each talker. F2 values (in Hz) at vowel midpoint were examined as a function of "context condition" (isolated, bilabial, alveolar) and "vowel type" ([i], [u], [a]). For Section 3.2, a 2x3 two-way multivariate analysis of variance was performed for each talker. F2 values (in Hz) at five measurement points of disyllables at normal speaking rate were examined as a function of "consonant context" (bilabial, alveolar) and "vowel type" ([i], [u], [a]). For Section 3.3.1 of the results, a 2x2x3 multivariate analysis of variance was performed for each talker. Durations (in milliseconds) of various portions of the CVC phrase (schwa, closure, VOT, vowel, and CVC) were examined as a function of “rate”, “consonant” and “vowel”. For Section 3.3.2 of the results, six 2x2x3 multivariate analyses of variance were performed, one for each talker. F2 values at five measurement points of disyllables were examined as a function of "consonant context" (bilabial, alveolar), "rate" (normal, fast) and "vowel type" ([i], [u], [a]). For Section 3.4 of the results, one 6x2x3 multivariate analyses of variance was performed where data was averaged across subjects at comparable rates, i.e. data for hearing talkers encompassed the set of disyllables uttered at normal speaking rate. Data for deaf talkers encompassed the set of disyllables uttered at fast speaking rate. The F2 values at each of five measurement points of the disyllables was analyzed as a function of "subject" (H1, H2, H3, D1, D2, D3), "consonant context" (bilabial, alveolar) and "vowel type" ([i], [u], [a]) .

Since both the main effects and the interactions among the independent variables yielded significant results, emphasis was placed on the planned comparisons where effects were looked at separately for each consonant-vowel combination. For Sections 3.2 and 3.3.2, two main types of planned comparisons were generated from the same MANOVA (2x2x3). One set contrasted disyllables that varied in vowel context but contained identical consonant environments (e.g. /∂bib/-/∂bub/). The other set contrasted disyllables that varied in consonant context but contained identical vowel environments (/∂bib/-/∂did/).

To consider the planned comparisons as post-hoc, a Bonferroni procedure, using a .005 level of significance was performed. In this procedure each of the planned comparisons are tested at the .005 level of significance (the level of significance is a .05/10 where 10 is the number of comparisons). Thus, the overall probability of making one or more type I errors for all planned comparison tests is at most .05 (Alan Gross, Personal Communication).

The analyses of variance are presented in appendixes A-E. Appendix A summarizes the results of six 3x3 two-way Anovas in Section 3.1, Appendix B summarizes the results of six 2x3 two-way Manovas in Section 3.2 of the results, Appendix C summarizes the results of six 2x2x3 three-way Manovas in Section

3.3.1 of the results, Appendix D summarizes the results of six 2x2x3 three-way Manovas in Section 3.3.2 of the results, and Appendix E summarizes the results of a 6x2x3 three-way Manova in Section 3.4 of the results. Tables of planned comparisons, where the actual level of significance for each comparison is reported, are detailed in these appendixes. The tables in the "results" chapter usually report only the cases where planned comparisons reached or approached the chosen criterion for significance.

The following abbreviations are used consistently throughout the presentation of the results:

H= hearing talker ; D = deaf talker

∂= schwa; CVC = consonant-vowel-consonant syllable;

∂1= schwa onset; ∂2= schwa midpoint; ∂3= schwa offset;

Ton= transition onset; Vm= vowel midpoint

RESULTS

Section 3.1 examines the role of context on point vowels, section 3.2 examines the effects of vowel and consonant context on disyllables at normal speaking rate, section 3.3 examines the effect of speaking rate on coarticulation of disyllables and section 3.4 examines the effect of vowel separation on anticipatory coarticulation of disyllables.

3.1 CONTEXTUAL INFLUENCES ON POINT VOWELS

The topic of this section is the role of context in the speech of the hearing and the deaf talkers. Three sets of point vowels were produced by the hearing and the deaf talkers: a) sustained vowels (isolated condition) b) vowels embedded in a b_b consonant frame (bilabial condition) and c) vowels embedded in a d_d consonant frame (alveolar condition). Data consisted of acoustic measurements of the first and second formants at the vowel midpoints.

Section 3.1.1 examines the effects of consonantal context(s) on the acoustic space of point vowels as seen in F1/F2 plots in the above three conditions. Its purpose is to draw general conclusions about static and dynamic vowel production in relation to the hearing status. Section 3.1.2 provides a more systematic analysis of the coarticulatory effects of consonant context on point vowels in relation to the second formant only. Its purpose is to make inferences about articulatory coordination.

3.1.1 First and second formant frequencies for point vowels: principal effects of context and hearing status

The data presented in this section are not discussed in terms of statistical significance since they describe only gross patterns and provide data for subsequent sections.

The questions addressed here are:

1) What is the distribution in F1/F2 space of point vowels in the hearing and the deaf talkers of this sample?

2) What is the effect of context on each talker's distribution of point vowels [i], [u] and [a]?

3) What patterns are discerned if one examines the effects of context on the distribution of point vowels in relation to hearing status?

Table 3.1 shows the mean values of first and second formant for each of the six talkers in each context condition (isolated, bilabial, alveolar). The standard deviations for each of the means, over ten tokens, are shown in parenthesis. The mean values of Table 3.1 are plotted in Figure 1 which presents the vowel spaces for each talker in the hearing and the deaf group. In each of the six graphs of

Figure 3.1, the vowel spaces are shown, in F1/F2 plots, as triangles with three data points, the point vowels [i], [u] and [a]. Each graph contains data from a single talker in each of the three context conditions. The left panel shows data for the hearing talkers. The right panel shows data for the deaf talkers.

With respect to the hearing talkers, visual inspection of Figure 3.1 reveals the following:

1. In the isolated condition, vowel spaces are similar across the hearing talkers.

2. The hearing talkers show a markedly higher F2 mean for the vowel center [u] in alveolar than bilabial or isolated conditions (Table 3.1) which results in a shrinkage of the vowel triangle in the alveolar condition as compared to the bilabial and isolated conditions.

3. Two of the three hearing talkers have the widest distribution of point vowels in the isolated condition. Talker H2 shows the widest distribution of point vowels for the bilabial condition, but the distribution is quite similar to the isolated condition.

With respect to the deaf talkers, visual inspection of Figure 3.1 reveals the following:

1. The deaf talkers show different distributions from each other of point vowels in the F1/F2 acoustic space, both within and across context conditions.

2. The deaf talkers show more collapsed vowel spaces than the hearing talkers, either in the F1 or F2 dimension, or both.

3. Their isolated vowel space is more collapsed than their context-embedded vowel spaces (unlike the hearing talkers).

4. Two deaf talkers, D1 and D3, sometimes show a lower F2 for [u] in context-embedded conditions compared to isolated conditions that cannot be attributed to elongation of the vocal tract[15] (see the F1 and F2 patterns, at the top and bottom graph, on the right panel of Figure 3.1). The lower F2 for [u] in alveolar as compared to isolated conditions for D1 and D3 indicates an opposite effect from the one observed in the hearing talkers.

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[15] Note that the concurrence of F1 and F2 decrease is indicative of a specific articulatory event, i.e. vocal tract elongation. This can take place during the vowel production of the CVC as the lip-rounding consonant gesture coarticulates with the vowel gesture.

Two points are worth mentioning: a) Talkers D1 and D2 show the broadest dispersion of point vowels in the alveolar condition. Talker D3 shows similar vowel distributions in the bilabial and alveolar condition. b) Talkers D1 and D2 show relatively more collapsed vowel spaces in the F2 than F1 dimension. Talker D3 shows a more collapsed vowel space in the F1 than F2 dimension even though the context conditions differentiate well along F1.

TABLE 3.1: Average F1 and F2 values (in Hz) for vowel centers in three context conditions, i.e. isolated, bilabial and alveolar. The standard deviation is given in parenthesis. The data represent both the hearing and the deaf talkers.

Hearing Status	**Subjects**	**F1**			**F2**		
		i	**bib**	**did**	**i**	**bib**	**did**
H	H1	352 (21)	362 (16)	351 (15)	2323 (71)	2185 (70)	2211 (52)
E	H2	341 (29)	348 (28)	355 (29)	2245 (68)	2260 (44)	2279 (30)
A	H3	317 (33)	327 (28)	303 (30)	2158 (16)	2116 (57)	2120 (37)
R T		**u**	**bub**	**dud**	**u**	**bub**	**dud**
I A	H1	351 (13)	383 (20)	372 (13)	878 (24)	912 (40)	1321 (140)
N L	H2	425 (19)	380 (22)	371 (20)	1209 (59)	1122 (62)	1522 (62)
G K	H3	340 (18)	384 (18)	338 (34)	1044 (34)	1046 (35)	1603 (56)
E		**a**	**bab**	**dad**	**a**	**bab**	**dad**
R	H1	852 (52)	661 (41)	678 (30)	1328 (57)	1151 (29)	1172 (46)
S	H2	805 (51)	783 (17)	778 (44)	1264 (43)	1251 (29)	1301 (45)
	H3	762 (19)	727 (37)	702 (37)	1299 (30)	1226 (27)	1274 (38)
		i	**bib**	**did**	**i**	**bib**	**did**
D	D1	362 (26)	423 (40)	408 (39)	1715 (80)	1824 (87)	1770 (54)
E	D2	525 (76)	461 (51)	420 (43)	1461 (212)	1960 (111)	1925 (140)
A	D3	347 (20)	379 (23)	427 (40)	1703 (88)	1712 (63)	1751 (46)
F		**u**	**bub**	**dud**	**u**	**bub**	**dud**
T	D1	388 (39)	455 (52)	417 (39)	1543 (93)	1642 (51)	1475 (116)
A	D2	488 (32)	460 (30)	435 (58)	1247 (106)	1534 (113)	1309 (115)
L	D3	337 (34)	379 (23)	418 (46)	1294 (59)	864 (42)	913 (60)
K		**a**	**bab**	**dad**	**a**	**bab**	**dad**
E	D1	696 (24)	728 (30)	739 (35)	1235 (39)	1201 (31)	1243 (29)
R	D2	758 (45)	728 (12)	733 (24)	1434 (29)	1476 (76)	1468 (56)
S	D3	520 (36)	480 (41)	521 (37)	1250 (81)	1484 (36)	1522 (77)

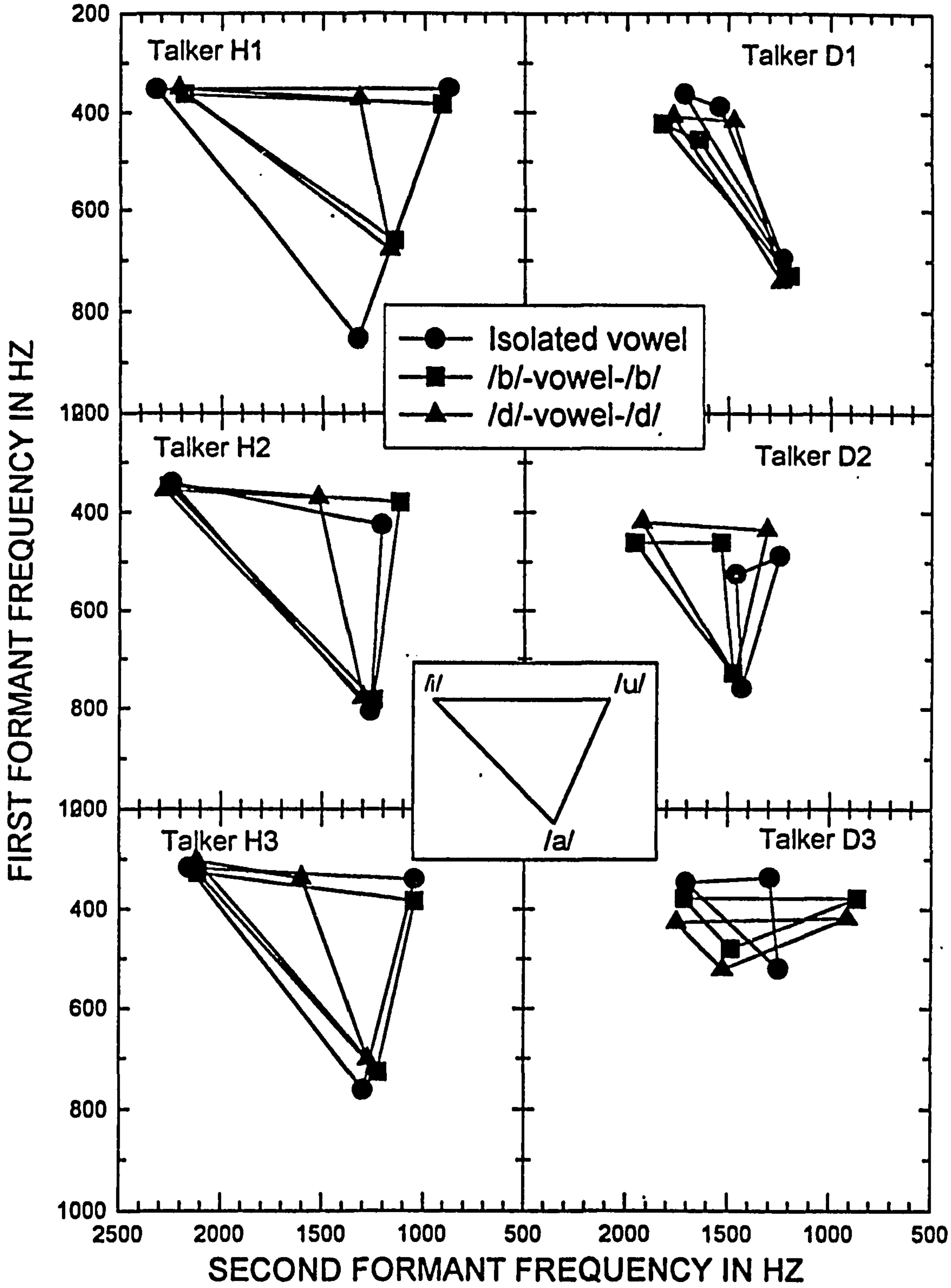

Figure 3.1: Second versus first formant frequencies for 3 vowels in 3 contexts, for 3 hearing and 3 deaf talkers.

3. 1.2 Coarticulation in the stressed syllable -- effects of hearing status and consonant context on the second formant frequencies of the point vowels.

The specific purpose in this section is to make inferences about coarticulation within the stressed syllable.

The questions addressed are:

1) Are the hearing talkers more likely than the deaf talkers to show significant context-conditioned F2 differences at vowel midpoint?

2) Are context effects in the expected direction in both groups, i.e. a lower midvowel F2 as a result of lip rounding in bilabial context and a higher midvowel F2 as a result of tongue fronting in alveolar context?

Statistical treatment was made in order to qualify statements about F2 differences of vowel centers across context conditions. Six 3x3 two-way univariate factorial analyses were performed, each on the token data of each talker. In the 3x3 two-way Anova, the F2 means at the vowel midpoint were analyzed as a function of context condition (isolated vs. bilabial, isolated vs. alveolar, bilabial vs. alveolar) and vowel type ([i], [u], [a]) (Appendix A). The ten replications of each token provided a "within cell" estimate of variance. Since both main effects and interactions were significant, pairwise comparisons between context conditions for a given vowel type were made.

Table 3.2 shows the F ratios and p level of significance for pairwise F2 comparisons of vowel centers in each of three conditions: a) isolated vs. bilabial b) isolated vs. alveolar and c) bilabial vs. alveolar. The top half of Table 3.2 shows data for the hearing talkers. The bottom half shows data for the deaf talkers. The asterisks mark significant p levels according to the Bonferroni criterion (.005). The arrows attached in each pairwise comparison specify the direction of significant F2 difference, i.e. lower or higher. Figure 3.2 shows the average F2 values at vowel midpoint (ordinate) for each of the three conditions, i.e. isolated, bilabial and alveolar (abscissa). The figure contains nine graphs which plot the data for each the deaf talker in relation to the group of the hearing talkers (shaded area) and for each vowel, [i], [u], [a]. Data for a given vowel center across talkers are shown horizontally. Data for a given talker across vowel centers are shown vertically.

3.1.2.1 A quantitative comparison of coarticulatory changes in hearing vs. deaf talkers. F2 patterns in isolated vs. bilabial vs. alveolar context.

A count of significant F2 differences (at .005 level of significance) at vowel midpoint as a function of context was made from Table 3.2. There are almost as many significant context effects in the deaf talkers (total= 11) as in the hearing (total= 12). This result does not change if one adopts a lower statistical criterion.

3.1.2.2 A qualitative comparison of coarticulatory changes in hearing vs. deaf talkers.

The direction of significant F2 difference as a function of context condition was examined for each talker across groups.

Inspection of the statistically significant patterns in the hearing data (Table 3.2) and Figure 3.2 indicate that

1. For talker-specific vowel centers, the hearing talkers show a lower F2 at the vowel center in the bilabial as compared with the isolated condition. Talkers H1 and H3 show this pattern for [i] and [a] whereas talker H2 shows it for [u]. Coarticulatory effects of lip rounding in the bilabial context are inferred.

2. The hearing talkers uniformly show a higher F2 in /dud/ as compared to /u/. Lingual coarticulatory effects are inferred to take place in the alveolar context.

3. The hearing talkers uniformly show a higher F2 in /dud/ as compared to /bub/. Two hearing talkers show this effect for [a] center as well. Again, lingual coarticulatory effects are inferred in the alveolar context.

4. Talker H1 shows significant F2 lowering at vowel centers: a) /did/ as compared to /i/ and b) /dad/ as compared to /a/. The first pattern is not in the expected direction. The second pattern may be the outcome of atypical lip rounding of /d/ where the lip rounding gesture is coarticulated with the lingual gesture for the [a] production (Gelfer, Bell-Berti & Harris., 1989). This account is supported by the F1 pattern. Nevertheless, it is important to note that, although

statistical tests most often reveal systematic effects of the examined data, the magnitude of these effects is sometimes small and may be of questionable perceptual salience.

Inspection of the statistically significant patterns in the deaf talkers (Table 3.2) and Figure 3.2 indicate that:

1. For talker-specific vowel centers, the deaf talkers show a higher F2 for vowel centers in bilabial as compared with the isolated condition. Hence, in talkers D1 (left panel of Fig. 3.2) and D2 (center panel of Fig. 3.2), this is seen for [i] and [u] centers. In talker D3 (right panel of Fig. 3.2), it is observed for the [a] center. The pattern is opposite to the one observed in the hearing talkers -- with the exception noted in D3 where the F2 is lower in /bub/ than /u/.

2. The deaf talkers uniformly show a higher F2 for [i] in the alveolar as compared with the isolated condition. This pattern is not observed in the hearing talkers. Moreover, two deaf talkers show a lower F2 in /dud/ than /u/, a pattern opposite to the one seen in the hearing talkers.

3. The deaf talkers show effects of bilabial vs. alveolar context, primarily for the [u] center, however, the direction of these context-specific effects is not consistent across the deaf talkers as it is in the hearing talkers. Talkers D1 and D2 show a higher F2 mean for /bub/ than /dud/. A reverse effect is seen for talker D3 where the F2 mean for /dud/ is higher than /bub/. Talker D1 shows a higher F2 mean for /bib/ than /did/.

Table 3.2: Pairwise planned comparisons of F2 values at vowel midpoint among context conditions: a) isolated vs. bilabial b) isolated vs. alveolar c) bilabial vs. alveolar. The arrows show the direction of F2 difference, i.e. lower or higher in relation to the second member of each pairwise comparison.

Subjects	Utterances, isol. vs. bilabial	F2 at vowel midpoint	Utterances, isol. vs. alveolar	F2 at vowel midpoint	Utterances, bilabial vs. alveolar	F2 at vowel midpoint
H1	/i/-/bib/	F= 20.98, p< .001* ↓	/i/-/did/	F= 13.93, p< .001*↓	/bib/-/did/	F= .72, p< .399
	/u/-/bub/	F= 1.28, p< .261	/u/-/dud/	F= 217.22, p< .001* ↑	/bub/-/dud/	F= 185.17, p< .001↑
	/a/-/bab/	F= 34.59, p< .001* ↓	/a/-/dad/	F= 27.06, p< .001* ↓	/bab/-/dad/	F= .46, p< .499
H2	/i/-/bib/	F= .41, p< .522	/i/-/did/	F= 2.21, p< .149	/bib/-/did/	F= .66, p< .418
	/u/-/bub/	F= 14.55, p< .001* ↓	/u/-/dud/	F= 187.12, p< .001* ↑	/bub/-/dud/	F= 306.01, p< .001* ↑
	/a/-/bab/	F= .28, p< .595	/a/-/dad/	F= 2.74, p< .102	/bab/-/dad/	F= 4.79, p< .031
H3	/i/-/bib/	F= 5.69, p< .019	/i/-/did/	F= 4.67, p< .034	/bib/-/did/	F= .05, p< .823
	/u/-/bub/	F= .02, p< .891	/u/-/dud/	F=1031.72, p< .001*↑	/bub/-/dud/	F=1022.88 , p< .001* ↑
	/a/-/bab/	F= 17.60, p< .001* ↓	/a/-/dad/	F= 2.05, p< .156	/bab/-/dad/	F= 7.64, p< .007
D1	/i/-/bib/	F= 11.97, p< .001* ↑	/i/-/did/	F= 3.11, p< .0816	/bib/-/did/	F= 2.88, p< .094
	/u/-/bub/	F= 9.82, p< .002* ↑	/u/-/dud/	F= 4.72, p .0328	/bub/-/dud/	F= 28.15, p< .001* ↓
	/a/-/bab/	F= 1.19, p< .279	/a/-/dad/	F= .06, p< .800	/bab/-/dad/	F= 1.81, p< .183
D2	/i/-/bib/	F= 90.50, p< .001* ↑	/i/-/did/	F= 78.51, p< .001* ↑	/bib/-/did/	F= .43, p< .516
	/u/-/bub/	F= 29.86, p< .001* ↑	/u/-/dud/	F= 1.39, p< .242	/bub/-/dud/	F= 18.36, p< .001* ↓
	/a/-/bab/	F= .64, p< .424	/a/-/dad/	F= .41, p< .522	/bab/-/dad/	F= .03, p< .873
D3	/i/-/bib/	F= .09, p< .765	/i/-/did/	F= 2.86, p< .095	/bib/-/did/	F= 1.93, p< .168
	/u/-/bub/	F= 230.36, p< .001* ↓	/u/-/dud/	F= 180.86, p< .001* ↓	/bub/-/dud/	F= 3.00, p< .088
	/a/-/bab/	F= 68.71, p< .001* ↑	/a/-/dad/	F= 93.06, p< .001* ↑	/bab/-/dad/	F= 1.84, p< .178

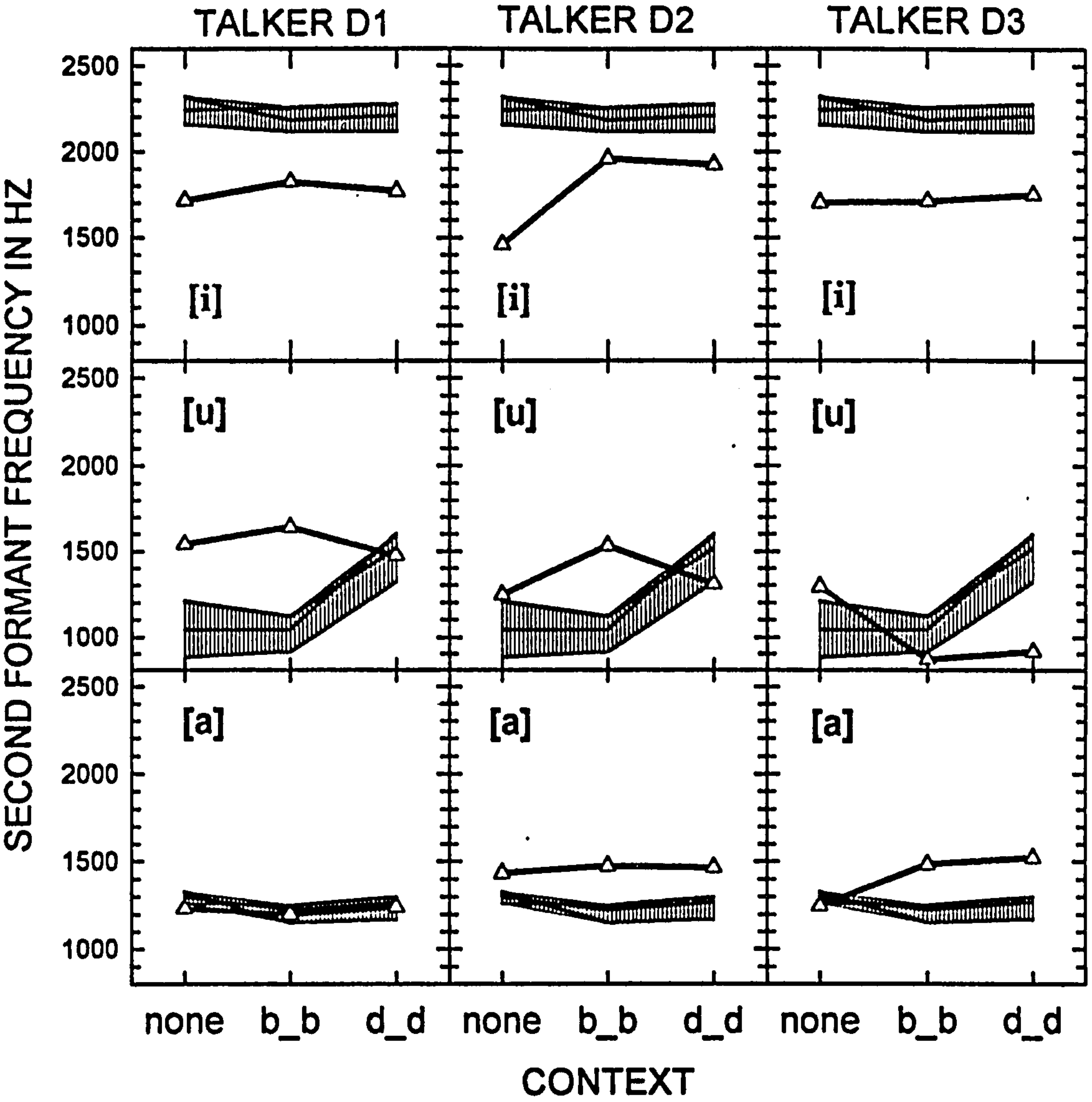

Figure 3.2: Each graph shows the F2 data at vowel midpoint (in Hz) for each deaf talker and the hearing talkers (shaded area) as a function of context. The F2 data are shown separately for [i], [u], [a].

3.1.3. Discussion and conclusions

In section 3.1.1., an examination of distributions of point vowels in relation to the presence or absence of context indicated different overall patterns across talkers that differ in hearing status. Two of the three hearing talkers showed their largest distribution of point vowels in the isolated condition. Vowels uttered in a context-free, sustained fashion occupy more extreme positions in the F1/F2 space, and presumably in the vocal tract, than their context-embedded counterparts. The deaf talkers' vowel spaces were uniformly smaller in the isolated condition than in CVC context.

With respect to the coarticulatory patterns (section 3.1.2), the deaf talkers show as many instances of significant F2 shifts with context as the hearing talkers[16]. However, in the hearing talkers, the F2 shifts occur in predicted directions, whereas in the deaf talkers, they do not. These differences are summarized below:

1) For talker-specific vowel centers, the hearing talkers show a lower F2 in bilabial than in isolated conditions. The pattern is probably to be attributed to

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[16] One may not conclude that the F2 context-conditioned differences are consistently smaller in the deaf than the hearing talkers since the vowel distributions across the two groups are not directly comparable. That is, the hearing talkers show a greater separation between vowel centers [i],[a],[u], and therefore greater absolute F2 context-conditioned differences.

coarticulation of a lip rounding gesture for consonant production (/b/) with the lingual gesture for vowel production -- the inference for lip rounding is supported by the observed lower F1 means for those vowel centers in bilabial conditions as compared with the isolated condition. For talker-specific vowel centers, the deaf talkers tended to show a higher F2 in bilabial context, an effect not predicted from the hearing pattern.

2) With respect to the effects of alveolar context, the hearing talkers show a higher F2 for back vowel centers, especially [u], in alveolar compared to bilabial or isolated conditions. Physiological inferences from this F2 pattern suggest coarticulation of tongue dorsum ([u] or [a] constriction) with tongue blade (/d/ contact) where the former subarticulatory parameter shifts anteriorly. The deaf talkers do not exhibit the above pattern in a consistent way. Instead, they show trends for higher F2 for [u] in bilabial compared to alveolar conditions (in two the deaf talkers only) and for a higher F2 of /i/ in alveolar compared to isolated conditions.

3) In two deaf talkers (D1 and D3 in the middle panel of Fig. 3.2), the [u] center sometimes shows a lower F2 for context-embedded than isolated conditions that can not be attributed to lip rounding (elongation of the vocal tract). As mentioned, the F1 pattern does not support a physiological explanation of lip rounding at the vowel center. One infers a tendency for more posterior lingual

constriction locations for [u] in context-embedded than isolated productions.

In conclusion, in most cases, the deaf talkers show *idiosyncratic* contextual influences, whereas the hearing talkers show similar influences.

3.2. COARTICULATION IN DISYLLABLES

Coarticulation is examined by looking at F2 differences between disyllable pairs at five measurement points, i.e. schwa onset, schwa midpoint, schwa offset, transition onset and vowel midpoint. The disyllables are paired successively to contrast vowel and then consonant context, leading to two types of analyses: coarticulation of schwa /ə/ conditioned by vowel context, and coarticulation of vowels (schwa /ə/ and stressed vowels) conditioned by consonant context. The greater the F2 difference between contrastive disyllables at given measurement points the greater the coarticulation. The earlier the measurement point at which there is a significant F2 difference the longer the temporal anticipatory extent of coarticulation. The main focus is anticipatory coarticulation, as measured during the schwa.

Data are graphed and analyzed with respect to statistical significance. Six 2x3 multivariate factorial analyses are performed on the token data of each talker (see Appendix B). Planned comparisons examine the significance of each contrast separately. Two sets of planned comparisons are generated for each 2x3 Manova. The coarticulation of vowels is examined via planned comparisons of disyllable contrasts with identical consonant environments but different vowel context. The coarticulation of consonants is examined via planned comparisons of disyllable contrasts with identical vowel environments but different consonants.

Tables 3.3-3.8 present the raw data for sections 3.2, 3.3 and 3.4, i.e. the average F2 values and standard deviations at five measurement points throughout the disyllables, for each speaking rate, "normal" and "fast" separately. Each table presents the data of a single talker.

Table 3.3: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for hearing talker H1.

Hearing subject H1		Normal rate					Fast rate				
Consonant	**Vowel**	∂1	∂2	∂3	**Ton**	**Vm**	∂1	∂2	∂3	**Ton**	**Vm**
/b/	/i/	1275	1257	1199	1950	2185	1313	1274	1249	1934	2165
		50	**49**	**51**	**33**	**70**	**46**	**47**	**76**	**43**	**64**
/b/	/u/	1224	1175	1093	976	912	1228	1177	1068	974	947
		76	**99**	**119**	**46**	**40**	**64**	**64**	**55**	**62**	**44**
/b/	/a/	1224	1160	1096	1139	1151	1218	1155	1090	1138	1207
		43	**42**	**24**	**30**	**29**	**18**	**30**	**31**	**41**	**46**
/d/	/i/	1379	1449	1497	2018	2211	1442	1476	1522	1977	2207
		62	**46**	**39**	**66**	**52**	**67**	**32**	**52**	**41**	**99**
/d/	/u/	1354	1418	1488	1732	1321	1389	1437	1486	1728	1517
		33	**32**	**42**	**61**	**140**	**54**	**52**	**42**	**70**	**66**
/d/	/a/	1355	1434	1492	1613	1172	1415	1445	1449	1546	1257
		76	**40**	**47**	**38**	**46**	**57**	**57**	**35**	**48**	**38**

Table 3.4: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for hearing talker H2.

Hearing subject H2		**Normal rate**					**Fast rate**				
Consonant	**Vowel**	**∂1**	**∂2**	**∂3**	**Ton**	**Vm**	**∂1**	**∂2**	**∂3**	**Ton**	**Vm**
/b/	/i/	1388	1330	1187	2061	2260	1496	1455	1350	2068	2222
		66	**44**	**45**	**69**	**44**	**43**	**27**	**76**	**68**	**50**
/b/	/u/	1277	1218	1108	1158	1122	1302	1235	1127	1243	1235
		35	**52**	**46**	**62**	**62**	**60**	**38**	**41**	**56**	**67**
/b/	/a/	1260	1218	1105	1102	1251	1227	1177	1116	1110	1254
		57	**55**	**50**	**40**	**29**	**51**	**43**	**41**	**36**	**35**
/d/	/i/	1595	1657	1675	2086	2279	1655	1686	1676	2057	2215
		78	**54**	**79**	**51**	**30**	**136**	**108**	**135**	**37**	**29**
/d/	/u/	1472	1549	1617	1825	1522	1597	1607	1615	1829	1667
		46	**35**	**68**	**26**	**62**	**39**	**37**	**44**	**52**	**70**
/d/	/a/	1490	1541	1581	1618	1301	1582	1591	1561	1613	1373
		59	**27**	**40**	**51**	**45**	**60**	**45**	**74**	**39**	**45**

Table 3.5: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for hearing talker H3.

Hearing subject H3		Normal rate					Fast rate				
Consonant	**Vowel**	**∂1**	**∂2**	**∂3**	**Ton**	**Vm**	**∂1**	**∂2**	**∂3**	**Ton**	**Vm**
/b/	/i/	1350	1319	1300	1904	2116	1447	1408	1350	1875	2081
		57	**58**	**53**	**53**	**57**	**41**	**42**	**57**	**49**	**58**
/b/	/u/	1261	1252	1182	1135	1046	1247	1247	1213	1134	1132
		38	**43**	**43**	**37**	**35**	**96**	**94**	**156**	**68**	**47**
/b/	/a/	1250	1224	1161	1156	1226	1252	1216	1192	1146	1248
		48	**40**	**59**	**27**	**27**	**37**	**60**	**79**	**24**	**34**
/d/	/i/	1545	1633	1653	1957	2120	1660	1681	1676	1967	2131
		81	**57**	**78**	**35**	**37**	**98**	**119**	**147**	**43**	**37**
/d/	/u/	1526	1604	1619	1792	1603	1575	1650	1616	1812	1635
		100	**81**	**60**	**70**	**56**	**51**	**42**	**58**	**46**	**34**
/d/	/a/	1509	1551	1556	1575	1274	1536	1555	1547	1610	1345
		69	**53**	**42**	**50**	**38**	**71**	**51**	**48**	**36**	**23**

Table 3.6: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for deaf talker D1.

Deaf subject D1		Normal rate					Fast rate				
Consonant	**Vowel**	∂1	∂2	∂3	**Ton**	**Vm**	∂1	∂2	∂3	**Ton**	**Vm**
/b/	/i/	1306	1328	1233	1550	1824	1395	1439	1277	1614	1748
		37	**63**	**101**	**76**	**87**	**60**	**77**	**75**	**123**	**60**
/b/	/u/	1274	1313	1201	1495	1642	1326	1317	1183	1475	1589
		60	**26**	**62**	**45**	**51**	**55**	**34**	**95**	**76**	**122**
/b/	/a/	1246	1224	1097	1112	1201	1304	1275	1138	1158	1263
		60	**30**	**43**	**30**	**31**	**69**	**63**	**81**	**48**	**64**
/d/	/i/	1294	1331	1439	1568	1770	1376	1479	1452	1583	1728
		28	**38**	**92**	**45**	**54**	**47**	**77**	**66**	**85**	**130**
/d/	/u/	1240	1277	1389	1516	1474	1292	1337	1439	1515	1314
		33	**45**	**75**	**60**	**117**	**57**	**58**	**57**	**78**	**65**
/d/	/a/	1207	1226	1303	1335	1243	1272	1313	1345	1423	1315
		23	**75**	**121**	**45**	**29**	**64**	**51**	**56**	**33**	**34**

Table 3.7: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for deaf talker D2.

Deaf subject D2		Normal rate					Fast rate				
Consonant	**Vowel**	∂1	∂2	∂3	**Ton**	**Vm**	∂1	∂2	∂3	**Ton**	**Vm**
/b/	/i/	1446	1466	1351	2121	1960	1574	1579	1269	1788	1904
		40	**62**	**132**	**61**	**111**	**117**	**137**	**124**	**269**	**364**
/b/	/u/	1457	1464	1245	1840	1534	1521	1514	1241	1510	1423
		50	**45**	**66**	**227**	**113**	**90**	**77**	**89**	**168**	**66**
/b/	/a/	1456	1433	1273	1446	1476	1483	1492	1262	1343	1499
		59	**48**	**100**	**69**	**76**	**58**	**86**	**109**	**121**	**61**
/d/	/i/	1449	1576	1637	1961	1925	1570	1661	1654	1844	1817
		71	**95**	**48**	**40**	**140**	**109**	**45**	**89**	**49**	**110**
/d/	/u/	1466	1534	1557	1653	1309	1559	1589	1562	1534	1274
		77	**118**	**76**	**125**	**115**	**75**	**66**	**91**	**79**	**82**
/d/	/a/	1430	1483	1651	1763	1468	1505	1628	1674	1737	1565
		64	**71**	**58**	**49**	**56**	**64**	**81**	**101**	**55**	**79**

Table 3.8: F2 average values (in Hz) and standard deviations (in boldface) of disyllables at normal and fast rate for deaf talker D3.

Deaf subject D3		Normal rate					Fast rate				
Consonant	**Vowel**	∂1	∂2	∂3	**Ton**	**Vm**	∂1	∂2	∂3	**Ton**	**Vm**
/b/	/i/	1446	1442	1203	1430	1712	1460	1449	1241	1461	1713
		73	**63**	**92**	**134**	**63**	**47**	**66**	**91**	**154**	**96**
/b/	/u/	1448	1459	1247	919	864	1483	1475	1349	951	902
		75	**95**	**98**	**65**	**42**	**84**	**87**	**89**	**49**	**65**
/b/	/a/	1445	1391	1099	1241	1484	1449	1421	1168	1300	1474
		93	**45**	**75**	**83**	**36**	**88**	**73**	**126**	**95**	**38**
/d/	/i/	1574	1621	1552	1671	1751	1601	1617	1516	1722	1811
		115	**90**	**91**	**53**	**40**	**99**	**65**	**110**	**90**	**82**
/d/	/u/	1457	1513	1396	1379	913	1484	1530	1441	1406	958
		78	**54**	**54**	**151**	**60**	**117**	**68**	**79**	**218**	**118**
/d/	/a/	1436	1511	1439	1463	1522	1480	1520	1452	1488	1525
		87	**71**	**61**	**32**	**77**	**84**	**67**	**64**	**39**	**63**

3.2.1. Coarticulation of stressed point vowels in disyllables at normal rate

The purpose of this section is to answer the following research questions:

1) What is the temporal extent of anticipatory coarticulation of vowel constrictions in deaf and hearing talkers?
2) Do hearing and deaf talkers show similar patterns of coarticulatory influence of a given consonant environment on vowel center separation[17]?

The difference between the F2 means, at the five points mentioned above, in disyllables containing contrastive vowel environments, [i]-[u], [i]-[a], [a]-[u], is presented in Table 3.9 for the hearing and the deaf talkers in bilabial and alveolar contexts respectively. These data are plotted in Figures 3.3-3.6, where each figure presents data for talkers by context. Note that the direction of F2 differences, i.e. positive (+) or negative (-), is indicated by deviation of data points above or below the zero line, e.g. in [a]-[u] pairs, when the F2 of disyllables with [u] center is higher than the F2 of disyllables with [a] center, then, the F2 difference is negative and falls below the zero line.

The analysis of patterns of anticipatory coarticulation at normal rate is summarized in Table 3.10, which presents the statistically significant patterns

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[17] Vowel separation is defined as the F2 difference between vowel centers.

(including patterns approaching statistical significance) between F2 means of contrasting disyllables, for both hearing and the deaf talkers. Statistical significance was calculated via planned comparisons performed on 2x3 Manovas (see Appendix B).

Emphasis is placed on the temporal onset of significant anticipatory coarticulation of vowel centers in disyllables, thus the data presented below are compared for the first measurement point at which the F2 means of contrasting disyllables are significantly different from each other.

Table 3.9: The mean F2 difference (in Hz) of disyllables contrasting in vowel context is presented for the hearing and the deaf talkers, at each measurement point, at normal rate. The second member of the disyllable pair is subtracted from the first one. The top panel shows bilabial disyllable pairs. The bottom panel shows alveolar disyllable pairs.

F2 DIFFERENCE IN HZ												
Disyllables	**Hearing talkers**	**Normal rate**					**Deaf talkers**	**Normal rate**				
		∂1	∂2	∂3	Ton	Vm		∂1	∂2	∂3	Ton	Vm
bib-bub	**H1**	51	82	105	973	1273	**D1**	32	15	32	55	182
	H2	110	112	79	903	1138	**D2**	-11	3	106	282	426
	H3	89	67	118	768	1070	**D3**	-1	-18	-44	511	847
bib-bab	**H1**	55	86	108	808	1039	**D1**	60	104	136	438	623
	H2	128	112	82	959	1009	**D2**	-10	33	78	676	483
	H3	100	95	139	748	890	**D3**	1	51	104	189	228
bab-bub	**H1**	-11	-24	-4	158	241	**D1**	-28	-89	-105	-383	-441
	H2	-17	0	-3	-56	129	**D2**	-1	-30	28	-394	-57
	H3	-11	-28	-21	21	180	**D3**	-2	-69	-148	322	620
did-dud	**H1**	26	32	13	286	889	**D1**	54	54	49	53	296
	H2	124	108	58	261	757	**D2**	-17	42	80	309	616
	H3	19	29	34	165	517	**D3**	117	108	156	292	838
did-dad	**H1**	19	11	-2	416	1037	**D1**	87	105	136	234	527
	H2	105	116	95	468	977	**D2**	20	93	-14	198	458
	H3	36	82	97	382	846	**D3**	138	110	113	207	229
dad-dud	**H1**	8	21	15	-115	-174	**D1**	-32	-51	-87	-181	-231
	H2	18	-8	-36	-206	-220	**D2**	-37	-51	94	111	159
	H3	-17	-53	-63	-218	-329	**D3**	-21	-3	43	84	609

3.2.1.1 Coarticulation of the stressed vowel by the hearing talkers.

Figure 3.3 shows the F2 differences at each measurement point between bilabial disyllables that have contrasting vowel environments. A zero line is plotted in every graph. For a particular measurement point, the greater the deviation from zero the greater the F2 difference, and therefore, the greater the coarticulation.

An inspection of Table 3.10 and Fig. 3.3 reveals:

1. In the top and middle panels, we see that all the hearing talkers show anticipatory vowel coarticulation of front vs. back vowel centers during schwa in bilabial disyllables. Significant anticipatory effects are uniformly seen at schwa onset (Table 3.11).

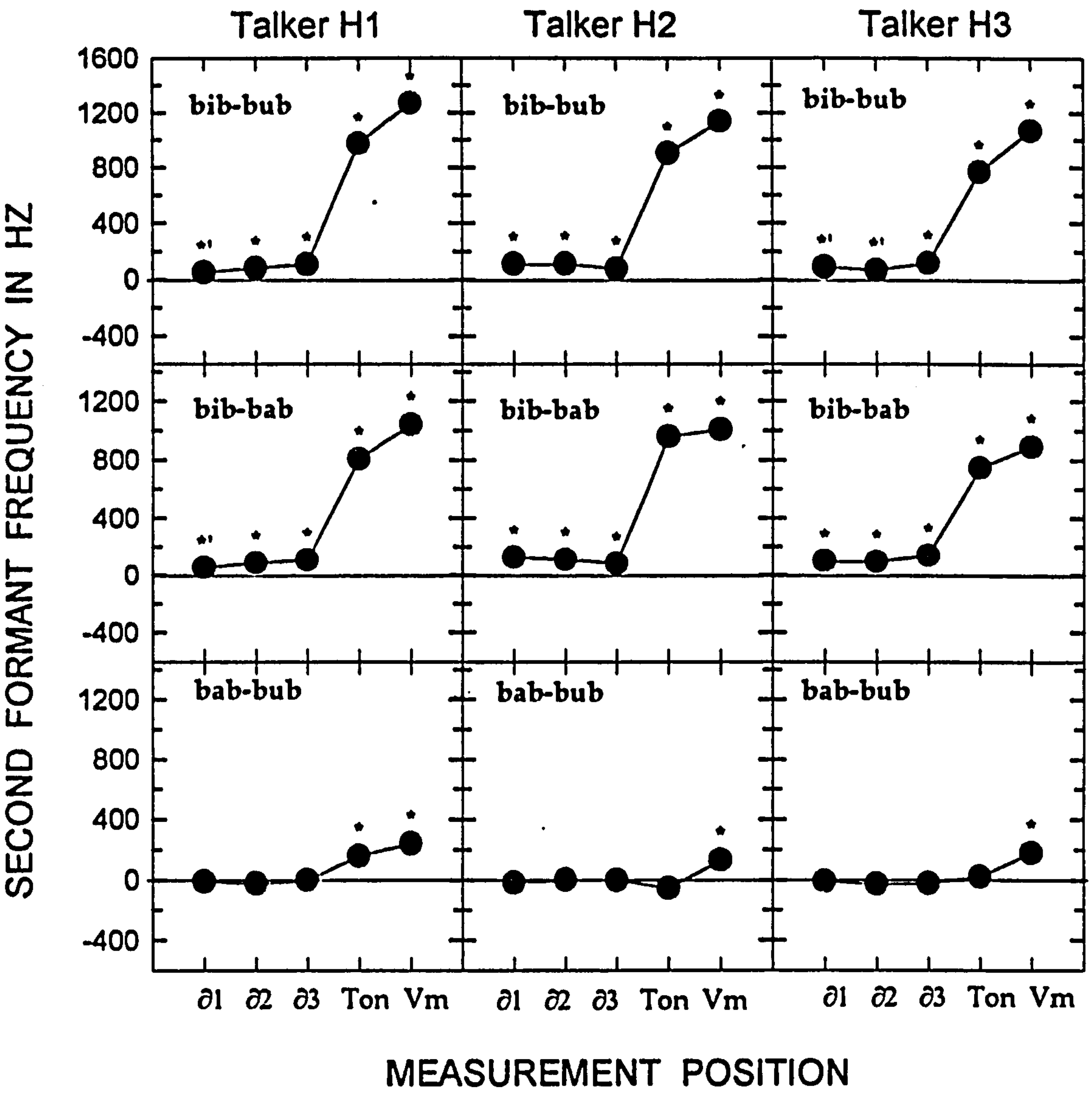
2. In the bottom panel, we see that the hearing talkers did not show anticipatory effects of low back ([a]) vs. high back ([u]) centers during schwa. Anticipation of vowel centers at transition onset is observed for H1 only.

Figure 3.4 shows the same data for alveolar disyllables. Inspection of Table 3.10 and comparison of Figures 3.3 and 3.4 reveals:

1. In the top and middle panels, we see that anticipatory coarticulation is less consistent for alveolar disyllables contrasted in front vs. back vowels (Table 3.10). Talker H2 shows anticipation at schwa onset across both bilabial and alveolar contexts.

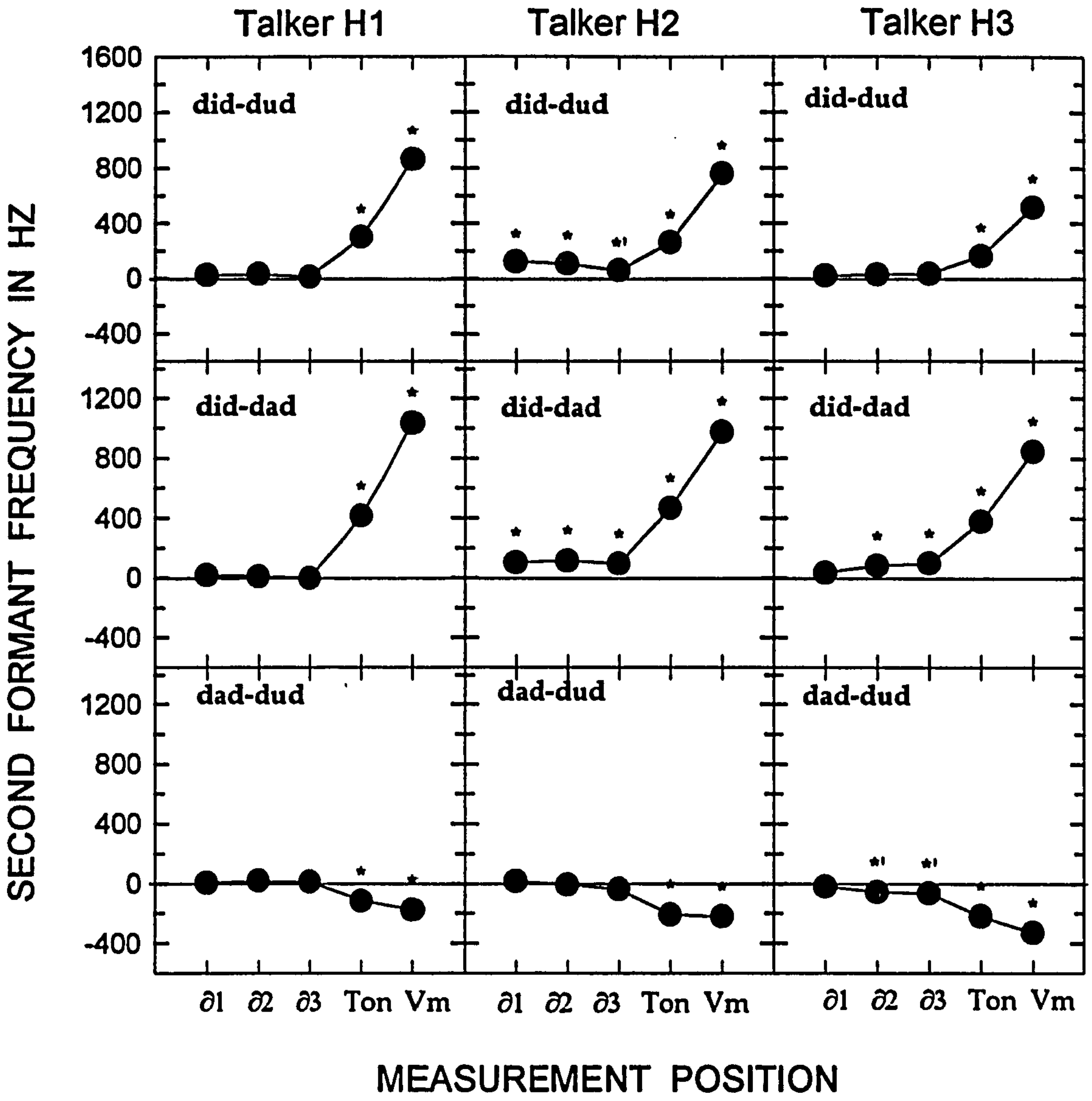
2. In the bottom panel, we see that anticipatory coarticulation occurs earlier in alveolar than bilabial disyllables contrasted in low back ([a]) vs. high back ([u]) vowels (Table 3.10). This is most evident in talker H3.

3. Within the stressed syllable, there are effects of consonant context on the magnitude and spectral order of vowel separation: vowel separation in front/back vowel contrasts is greater in bilabial than alveolar contexts. One observes higher F2 means in /∂dud/ than /∂dad/ and lower ones in /∂bub/ than /∂bab/.



ə 1 = schwa onset
ə 2 = schwa midpoint
ə 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.3: F2 differences at five measurement points among bilabial disyllables contrasted in vowel context -- hearing talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at the .05 level. The second member of the disyllable pair is subtracted from the first.



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.4: F2 differences at five measurement points among alveolar disyllables contrasted in vowel context -- hearing talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at the .05 level. The second member of the disyllable pair is subtracted from the first.

Table 3.10: Anticipatory coarticulation of vowel context in the hearing and the deaf talkers. Planned comparisons of F2 means of contrastive disyllables are shown with five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level (dotted areas).

Subjects	Disyllables	∂1	∂2	∂3	Ton	Vm	Disyllables	∂1	∂2	∂3	Ton	Vm
H1	/bib/-/bab/	*.0491	*	*	*	*	/did/-/dad/				*	*
H2	/bib/-/bab/	*	*	*	*	*	/did/-/dad/	*	*	*	*	*
H3	/bib/-/bab/	*	*	*	*	*	/did/-/dad/		*	*	*	*
	/bib/-/bub/	*.0097	*	*	*	*	/did/-/dud/				*	*
	/bib/-/bub/	*	*	*	*	*	/did/-/dud/	*	*	*.0248	*	*
	/bib/-/bub/	*.0054	*.0114	*	*	*	/did/-/dud/				*	*
	/bab/-/bub/				*	*	/dad/-/dud/				*	*
	/bab/-/bub/					*	/dad/-/dud/				*	*
	/bab/-/bub/					*	/dad/-/dud/		*.0420	*.0160	*	*
D1		*	*	*	*	*		*	*	*	*	*
D2				*.0445	*	*			*.0097		*	*
D3				*.0053	*	*		*	*	*	*	*
					*.0225	*		*.0065	*.0189		*.0282	*
				*.0072	*	*				*.041	*	*
					*	*		*	*	*	*	*
			*	*.0090	*	*		*.0464	*.0252	*.0287	*	*
					*	*				*.0170	*.0362	*
				(*)	*	*					*.0517	*

Note: the symbol " (*) " in talker D3's /bab/-/bub/ pair indicates a significant pattern in a direction opposite to the one expected for anticipation of vowel centers.

3.2.1.2 Coarticulation of the stressed vowel by the deaf talkers.

The F2 differences for disyllable pairs contrasted in vowel context are shown in Table 3.9. The vertical columns show data for each deaf talker and consonant environment. The rows show data at each measurement point.

Figure 3.5 plots the F2 differences of bilabial disyllable pairs contrasted in vowel context. Each column shows graphs for a single deaf talker. An inspection of Table 3.10 and Figure 3.5 indicates:

1. In bilabial disyllables contrasted in front/back vowels, early anticipation is seen for one talker (D1) in one comparison only, the high front ([i]) vs. low back ([a]) vowel contrast.

2. In bilabial disyllables, the same talker (Talker D1) shows anticipation of low back ([a]) vs. high back ([u]) vowels at schwa midpoint.

3. The deaf talkers exhibited patterns not observed in the speech of the hearing talkers. These are:

a) Talker D2 shows a large F2 difference in /∂bub/-/∂bab/ at transition onset only. The F2 difference diminishes greatly at vowel midpoint. Therefore, one concludes that D2 does not anticipate the vowel centers in /∂bab/-/∂bub/ contrast at transition onset. The F2 separation at transition onset can be attributed to carryover effects of the bilabial consonant, an idiosyncratic pattern of D2.

b) In talker D3, in /əbab/-/əbub/ during schwa, the F2 means for /əbub/ are higher than those for /əbab/ -- a negative F2 difference. However, the pattern reverses within the stressed syllable. One concludes that D3 does not anticipate the [a-u] contrast during schwa, even though the F2 pattern is statistically significant.

Figure 3.6 plots the F2 differences of alveolar disyllable pairs contrasted in vowel context. Each column shows graphs for a single deaf talker. An inspection of the Table 3.10 and Figure 3.6 indicates:

1. Two deaf talkers (D1 and D3) show anticipation of front vs. back vowels at schwa onset. A somewhat later onset of anticipation during schwa is observed for D2.

2. One talker (D1) shows anticipation of low back ([a]) vs. high back ([u]) vowels at schwa onset.

3. The coarticulatory effects within the stressed syllable did not follow the context-specific trends observed in the hearing talkers. Similar to the hearing talkers but unlike D2 and D3, one deaf talker D1 has a higher F2 in /ədud/ than /ədad/ at transition onset and vowel midpoint.

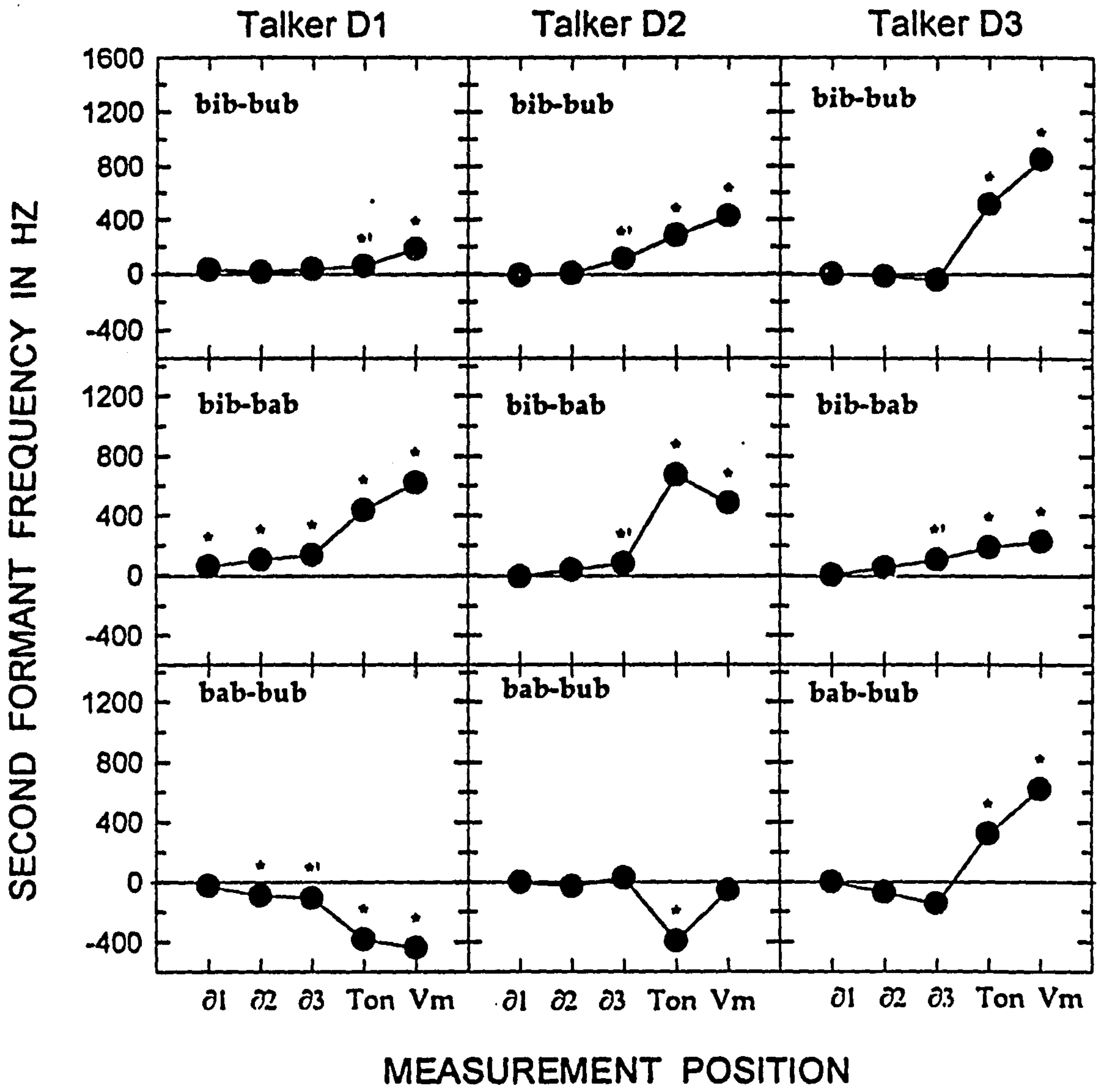
A comparison of Figures 3.5 and 3.6 in relation to Table 3.10 reveal that

1. Overall, the deaf talkers show earlier anticipation of vowel centers in alveolar than in bilabial context.

2. The anticipation of low back ([a]) vs. high back ([u]) vowel centers occurs earlier in alveolar than bilabial disyllables. This was noted for the hearing talkers as well.

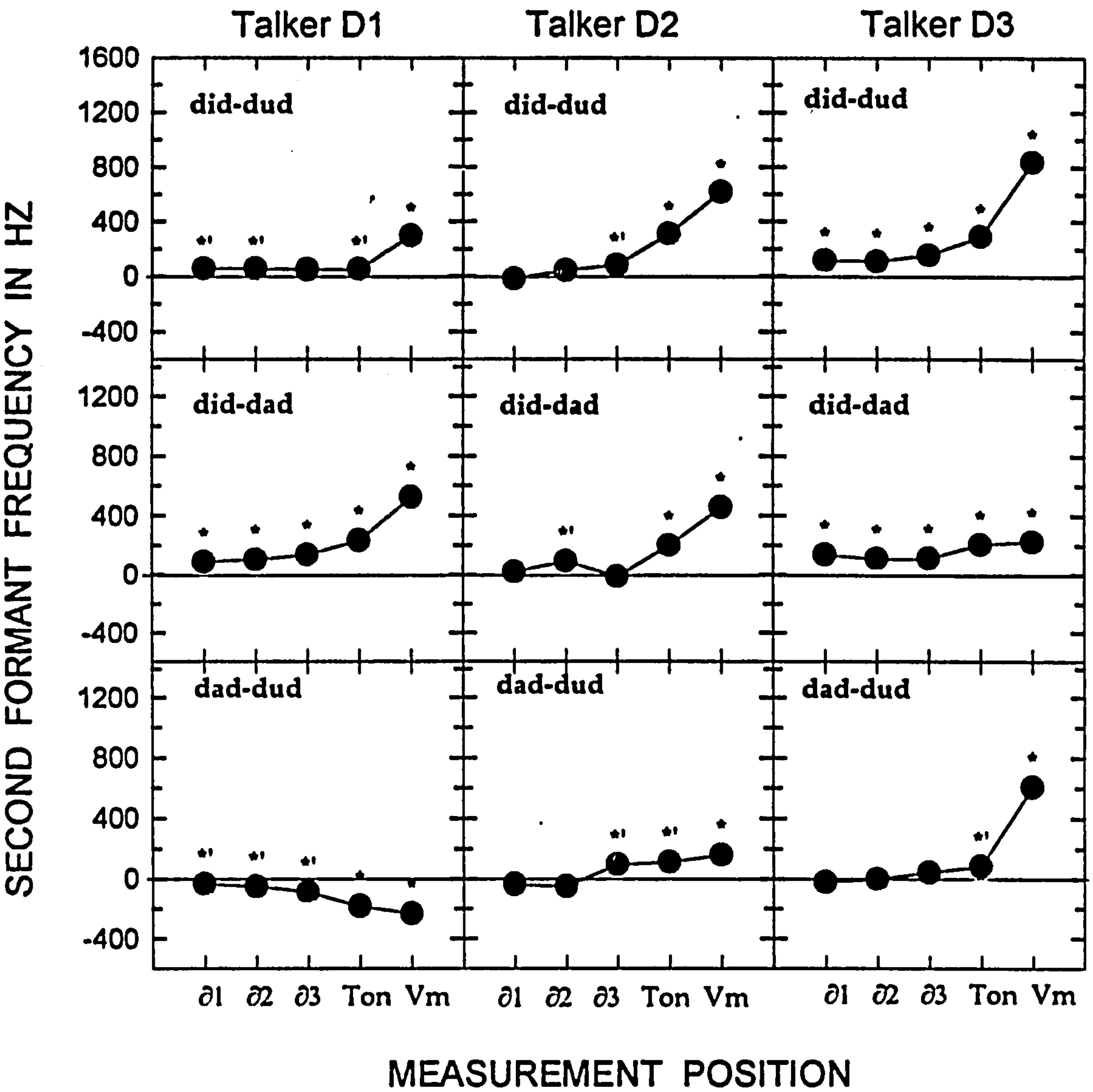
3. The deaf talkers do not show the context-specific coarticulatory influences at vowel midpoint seen in the speech of the hearing talkers, i.e. a lower F2 for /∂bub/ than /∂bab/ and a higher F2 for /∂dud/ than /∂dad/. Instead, some idiosyncratic patterns are noted. For example, talker D2 shows context-specific effects within the stressed syllable in that F2 in /∂bub/ is higher than in /∂bab/ and lower in /∂dud/ than /∂dad/.

4. In D1, the earlier anticipation of high front ([i]) vs. high back ([u]) vowel centers in alveolar than bilabial contexts is related to the greater vowel



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.5: F2 differences at five measurement points among bilabial disyllables contrasted in vowel context -- deaf talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at the .05 level. The second member of the disyllable pair is subtracted from the first.



ə 1 = schwa onset
ə 2 = schwa midpoint
ə 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.6: F2 differences at five measurement points among alveolar disyllables contrasted in vowel context -- deaf talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at the .05 level. The second member of the disyllable pair is subtracted from the first.

differentiation in the former context (see section 3.1.2).

3.2.1.3. Discussion and conclusions.

The earliest measurement positions at which the disyllable pairs are significantly different were examined across the two groups of subjects, i.e. hearing and the deaf talkers (Table 3.10).

In disyllables of varying vowel context and identical consonant environment, the comparison indicates that the time of anticipatory coarticulation onset, depends on the particular consonant-vowel composition of the disyllable. Thus, in bilabial disyllables contrasted in back/front vowels, i.e. /bib/-/bab/ and /bib-bub/ pairs, the hearing group shows generally earlier onset of anticipatory coarticulation than the deaf group. In bilabial disyllables contrasted in high/low back vowels, i.e. /bab/-/bub/, one member, D1, shows earlier anticipation than the hearing group. In alveolar disyllables the deaf talkers tended to show earlier onset of anticipatory coarticulation than the hearing group across vowel contexts.

The deaf talkers differed from the hearing talkers in the coarticulatory effects of a given consonant environment on back vowel centers. The hearing talkers were systematic in their lower F2 in /∂bub/ compared to /∂bab/ and their higher F2 in /∂dud/ compared to /∂dad/. The patterns of the deaf talkers were idiosyncratic.

3.2.2. Coarticulation of consonant context

The purpose of this section is to examine the coarticulation of vowels (schwa /ə/ and the stressed vowels [i], [u], [a]) conditioned by consonant context in hearing vs. deaf talkers at normal conversational rate. The research questions addressed are:

1) What is the temporal extent of anticipatory coarticulation of the schwa /ə/ conditioned by consonant context in deaf and hearing talkers?
2) What is the magnitude of effects of consonant context observed at transition onset of the stressed syllable in comparison with the magnitude observed during schwa in hearing and deaf talkers?

The difference of F2 means between disyllables with contrasting consonant context and identical vowel environment serves as a measure of coarticulation at each given measurement point. These data are presented below, in Table 3.11 and Figures 3.7-3.8.

The analysis of patterns of anticipatory coarticulation, for both the hearing and the deaf talkers, is summarized in Table 3.12. This table presents the measurement points at which the F2 means of disyllable pairs were significantly (or almost significantly) different.

3.2.2.1 Coarticulation of consonant context by the hearing talkers.

The top half of Table 3.11 presents the F2 differences between disyllables with contrasting consonant context for the hearing talkers for each measurement point and for each vowel environment. Figure 3.7 plots these data with respect to the departure of the differences from zero. For a given measurement point, the greater the deviation of F2 difference from zero, the greater the coarticulation. The graphs in the horizontal plane present data for a given vowel environment across talkers. The graphs in the vertical plane show data for a given talker across vowel environments. The measurement locations at which the F2 means of disyllable pairs uttered by the hearing talkers were significantly different can be found in Table 3.12 according to planned comparisons of a 2x3 MANOVA (Appendix B).

Inspection of Figure 3.7 and Table 3.12 indicate that:

1. The hearing talkers show anticipatory effects of consonant context beginning at schwa onset.

2. The hearing talkers show a coarticulatory effect of consonant context at the transition onset, for disyllables containing back vowels. Only talker H1 also exhibits this effect for disyllables with vowel center [i].

3. The hearing talkers show a coarticulatory effect of consonant context at the midpoint of stressed high back vowel center ([u]).

4. Throughout the disyllable, the F2 means are higher in alveolar than bilabial disyllables, as expected.

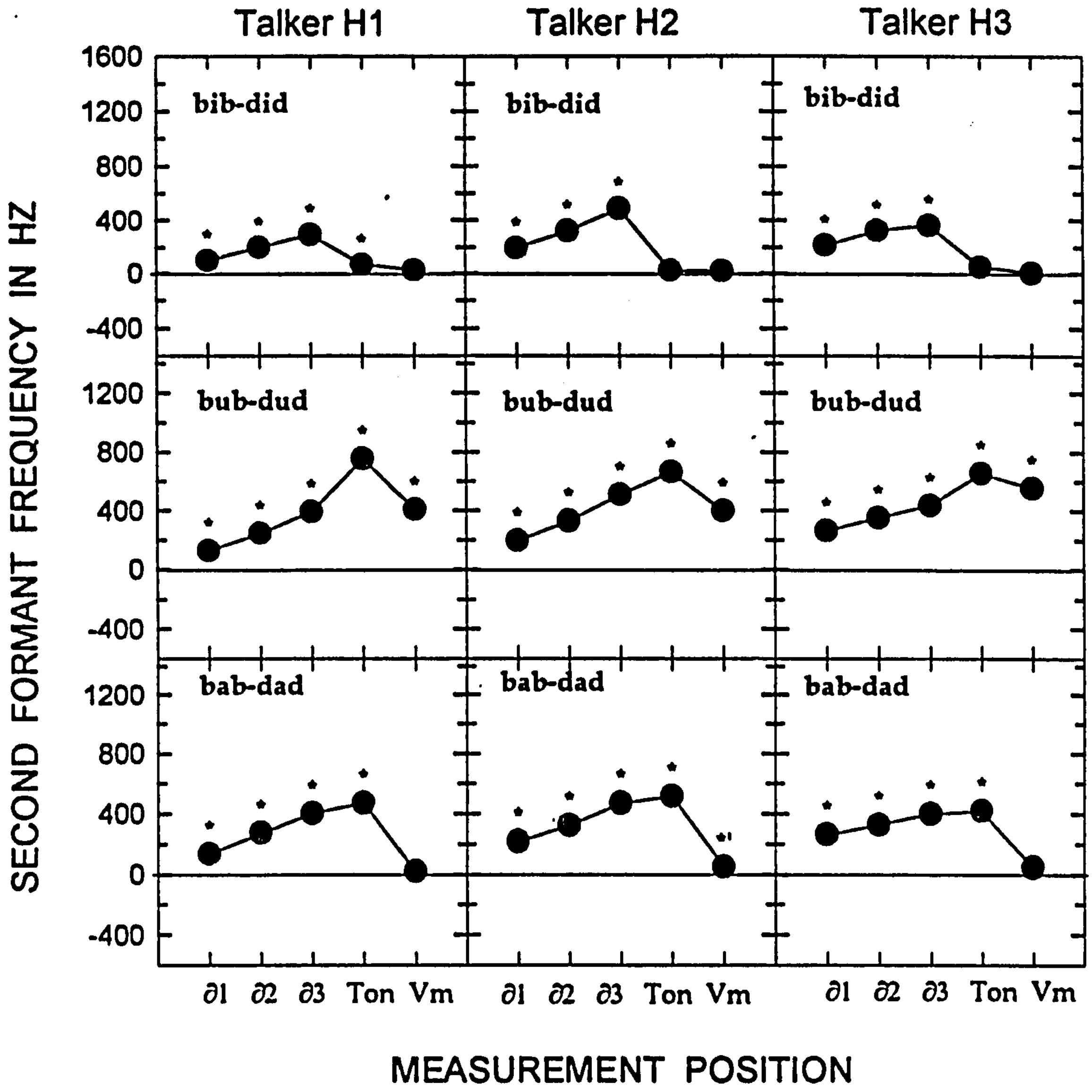
Furthermore, the magnitude of anticipatory vs. carryover coarticulatory effects of consonant context was examined by comparing the absolute size of F2 differences manifested during schwa (schwa midpoint and schwa offset) and transition onset (Table 3.13). The comparison shows that:

1. For disyllable contrasts containing either back vowel ([u] or [a]), the size of F2 differences is greater at transition onset than during schwa, across the hearing talkers, that is, carryover effects are larger in magnitude than anticipatory effects of consonant context.

2. In the /bib/-/did/ pair, the F2 difference at transition onset was smaller than during schwa. It is concluded that in the /bib/-/did/ pair carryover effects of consonant context at transition onset were smaller than anticipatory ones.

Table 3.11: The mean F2 difference (in Hz) of disyllables contrasting in consonant context is presented for the hearing and the deaf talkers, at each measurement point, at normal rate. The data for the hearing talkers is presented in the top panel. The data for the deaf talkers is presented in the bottom panel. The bilabial member of the disyllable pair is subtracted from the alveolar one.

Disyllables	**Hearing talkers**	**Normal rate**				
		ə1	ə2	ə3	Ton	Vm
bib/did	H1	100	198	293	68	26
	H2	194	321	489	25	19
	H3	214	323	362	53	4
bub/dud		129	243	395	756	409
		195	331	509	667	400
		266	352	438	657	557
bab/dad		136	273	403	474	20
		217	324	471	516	50
		262	327	399	419	48
Disyllables	**Deaf talkers**	**Normal rate**				
		ə1	ə2	ə3	Ton	Vm
bib/did	D1	-14	-9	204	19	-54
	D2	0	118	304	-160	-4
	D3	150	184	352	241	39
bub/dud		-35	-36	188	21	-168
		10	70	312	-187	-225
		9	54	149	461	49
bab/dad		-36	2	199	223	42
		-29	50	370	317	-8
		-17	120	338	223	38



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.7: F2 differences at five measurement points among disyllables contrasted in consonant context. Data for hearing talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at .05 level. The bilabial utterance is subtracted from the alveolar one.

TABLE 3.12: Coarticulation of consonant context in the hearing and the deaf talkers Planned comparisons of F2 means in bilabial vs. alveolar disyllables at schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). Anticipatory coarticulation is shown during schwa. The gray area represents coarticulation within the stressed syllable.

disyllables	**hearing talkers**	∂1	∂2	∂3	**Ton**	**Vm**	**deaf talkers**	∂1	∂2	∂3	**Ton**	**Vm**
/bib/-/did/	**H1**	*	*	*	*		**D1**			*		
/bib/-/did/	**H2**	*	*	*			**D2**		*	*	*	
/bib/-/did/	**H3**	*	*	*			**D3**	*	*	*	*	
/bub/-/dud/		*	*	*	*	*				*		*
/bub/-/dud/		*	*	*	*	*			***.0476**	*	*	*
/bub/-/dud/		*	*	*	*	*				*	*	***0517**
/bab/-/dad/		*	*	*	*					*	*	
/bab/-/dad/		*	*	*	*	***.0219**				*	*	
/bab/-/dad/		*	*	*	*				*	*	*	

Table 3.13: Absolute F2 differences (in Hz) between disyllable pairs with contrasting consonant context. Data from the hearing talkers.

F2 difference in Hz				
/bib/-/did/	**Subjects**	**∂2**	**∂3**	**Ton**
	H1	198	293	68
	H2	321	489	25
	H3	323	362	53
/bub/-/dud/	**Subjects**	**∂2**	**∂3**	**Ton**
	H1	243	395	756
	H2	331	509	667
	H3	352	438	657
/bab/-/dad/	**Subjects**	**∂2**	**∂3**	**Ton**
	H1	273	403	474
	H2	324	471	516
	H3	327	399	419

3.2.2.2. Coarticulation of consonant context by the deaf talkers.

The bottom half of Table 3.11 presents the F2 differences between disyllables with contrasting consonant context for the deaf talkers for each measurement point and vowel environment. Figure 3.8 plots these data in relation to its departure from zero. The measurement locations at which the F2 means of disyllable pairs uttered by the hearing talkers are significantly different can be found in Table 3.12, according to planned comparisons of a 2x3 MANOVA (see Appendix B).

Inspection of Figure 3.8 and Table 3.12 reveals the following:

1. The deaf talkers show limited anticipation of consonant context during schwa, particularly in disyllables containing back vowels. For deaf talker D1, anticipatory effects of consonant context are first noted at schwa offset, i.e. immediately before the consonant boundary.

2. Coarticulatory effects of consonant context at transition onset are observed for all talkers. The pattern is less uniform and different from the hearing pattern: effects of consonant context at transition onset are observed for talker-specific vowels and are idiosyncratic in nature (e.g. in D2, the F2 difference for /∂bib/-/∂did/ and /∂bub/-/∂dud/ at transition onset is negative. In D3, the same F2 difference is positive). Talker D1 shows coarticulatory effects of consonant context at transition onset for /∂bab/-/∂dad/ only.

3. Coarticulatory effects of consonant context at vowel midpoint are observed only in disyllables containing the high back vowel [u]. This result was also obtained for the hearing talkers. However, in the deaf talkers, the direction of these effects is talker-specific (i.e. higher F2 means for /bub/ than /dud/ for D1 and D2, lower F2 means for the same comparison in D3).

4. Additional idiosyncratic patterns are noted, e.g. for disyllables containing high vowel centers ([i] and [u]), deaf talker D2 has exhibited reversed patterns of influence of consonant context compared at schwa and at transition onset. The F2 difference for /∂bib/-/∂did/ and /∂bub/-/∂dud/ is positive at schwa midpoint but negative at transition onset.

Furthermore, the magnitude of anticipatory vs. carryover coarticulatory effects of consonant context was compared by contrasting the absolute size of F2 differences manifested during schwa (schwa midpoint and schwa offset) with the value obtained at transition onset (Table 3.14).

Table 3.14 presents the differences between F2 means of bilabial and alveolar disyllables at three locations, schwa midpoint, schwa offset and transition onset. In the deaf talkers, the magnitude of coarticulatory effects tends to be greater at transition onset compared to the schwa midpoint but smaller at transition onset compared to the schwa offset. This pattern is different from the one noted for the hearing talkers, since in their speech (the hearing talkers') carryover effects were consistently present for back vowel centers.

Table 3.14: Absolute F2 differences (in Hz) between disyllable pairs with contrasting consonant context. Data from the deaf talkers.

F2 difference in Hz				
	Subjects	∂2	∂3	Ton
/bib/-/did/	D1	9	204	19
	D2	118	304	160
	D3	184	352	241
	Subjects	∂2	∂3	Ton
/bub/-/dud/	D1	36	188	21
	D2	70	312	187
	D3	54	149	461
	Subjects	∂2	∂3	Ton
/bab/-/dad/	D1	2	199	223
	D2	50	370	317
	D3	120	338	223

3.2.2.3. Discussion and conclusions.

The deaf talkers exhibited less uniform coarticulatory patterns than the hearing talkers.

In disyllables of varying consonant environment and identical vowel composition (Table 12), the hearing group shows earlier anticipation, across all vowel contexts. Only deaf talker D3 shows comparable consonant anticipation to the hearing group in one disyllable contrast, /bib/-/did/.

Both the hearing and the deaf talkers exhibited instances of carryover effects of consonant context. However, the deaf talkers differed from the hearing talkers:

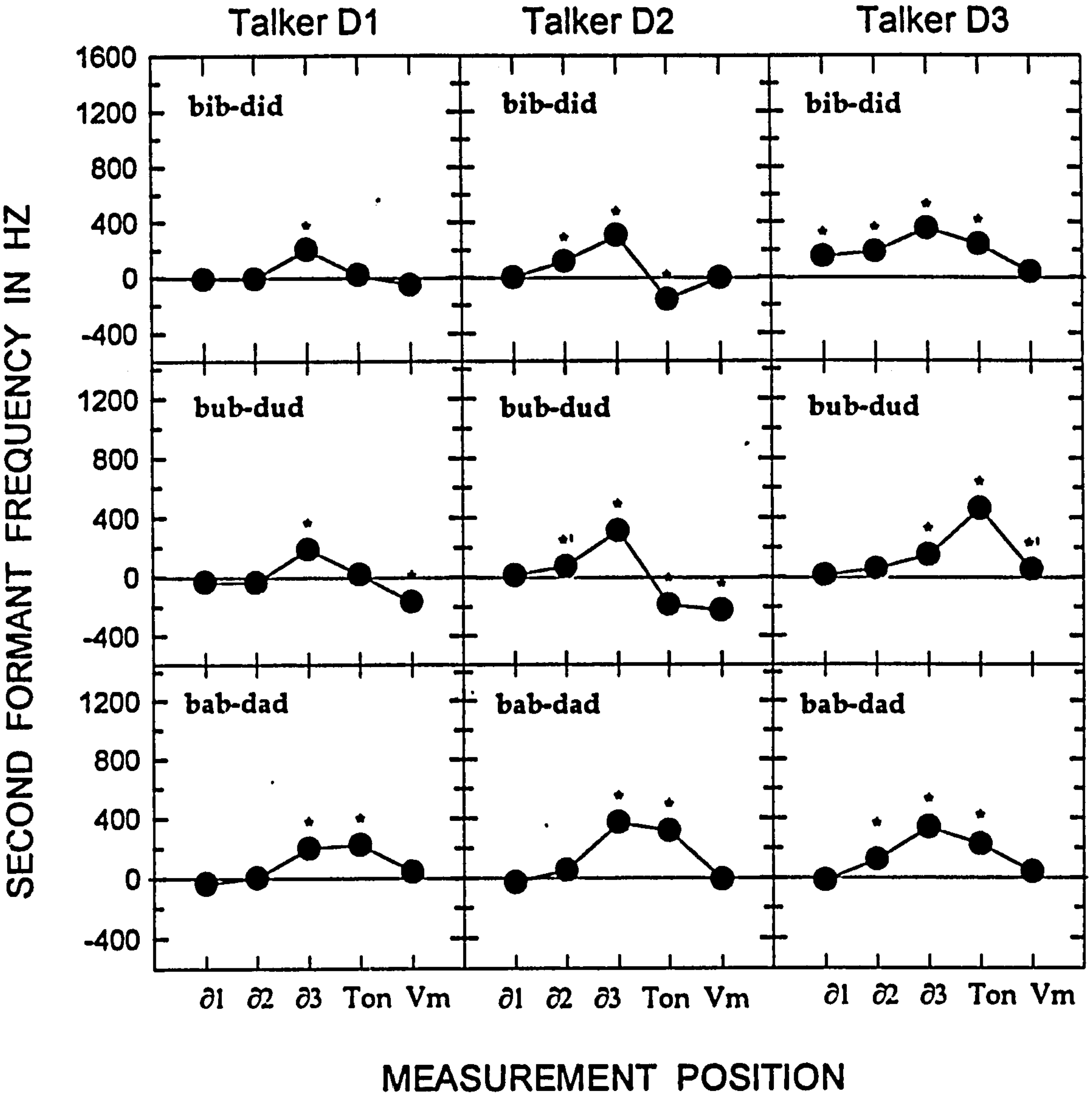
a) In the hearing talkers, significant carryover effects at transition onset occurred for back vowel centers. The pattern was less consistent for the deaf talkers.

b) With respect to the magnitude of anticipatory vs. carryover effects, in the hearing talkers, the F2 separation at transition onset was greater than the one seen during schwa. This was not observed consistently in the deaf talkers. The trend was for the F2 separation to be smaller at schwa midpoint than at transition onset but greater at schwa offset than at transition onset. One concludes that the spectral effects at the onset and offset of consonant formation differ in hearing and the deaf talkers.

Deaf talker D1 exhibited different patterns from the other deaf talkers:

a) he exhibited minimal anticipatory effects of consonant context.

b) he showed no effects of consonant context at transition onset for high vowel environments. Nevertheless, effects of consonant context were seen at [u] midpoint.



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

Figure 3.8: F2 differences at five measurement points among disyllables contrasted in consonant context. Data for deaf talkers. The asterisks indicate significant patterns (.005). The symbol (*') indicates significance at .05 level. The bilabial utterance is subtracted from the alveolar one.

3.3. RATE EFFECTS ON COARTICULATION

3.3.1 Durational changes with increases in speaking rate

The research questions addressed in this section are:

1) Do all talkers, the hearing and the deaf, show significantly smaller phrase and segment durations when paced to speak faster?

2) Is the amount of durational shortening at fast rate on a par with previous studies of hearing talkers at self-selected rates?

The means and standard deviations of durations across ten tokens of the same utterance at both normal and fast speaking rate are shown for each talker and segment in Table 3.15 below. The ratios of mean duration at fast to normal rate in Table 3.15 provide an estimate of percent decrease of mean durations with increases in speaking rate, according to the following formula:

$$(1.00 - \text{ratio}) \times 100 = \%,$$

i.e. the ratio of mean duration at fast to normal rate is subtracted from 1.00 and then multiplied by 100 to derive the percentage of decrease of mean durations as a function of increases in speaking rate.

$$\text{e.g. } (1.00 - 0.85) \times 100 = 15\%$$

The mean phrase durations of all talkers at normal vs. fast rates are plotted in Figure 3.9. The white bars show the phrase durations at normal rate. The dark bars show the phrase durations at fast rate.

An inspection of phrase durations, in the first two columns in Table 3.15 and Figure 3.9, indicates:

1. The hearing talkers speed up according to the predicted pattern -- their ratios are comparable with previous findings on durational changes at increased rates (Gay, 1978a).

2. The deaf talkers also speed up within the expected range. The percent decrease of individual deaf talkers falls both above and below that of the hearing talkers. Thus, at fast rate, two deaf talkers exhibit greater shortening than the hearing talkers. One deaf talker (D3) produces less durational shortening than the others -- although the percentage (15%) of durational shortening of D3's phrase is within the range seen in the hearing talkers in other studies (Gay, T. 1978a).

Examination of the univariate results of 2x2x3 MANOVAS performed on durations of various parts of the phrase "a CVC again", for each of the six talkers, indicated that all talkers, the hearing and the deaf, have significantly different durations at fast speaking rate as compared to normal speaking rate. The effect is highly significant ($p<.00001$) for all phrase parts (schwa, closure, stressed vowel, stressed syllable, phrase) except Voice Onset Time (VOT) (see Appendix C).

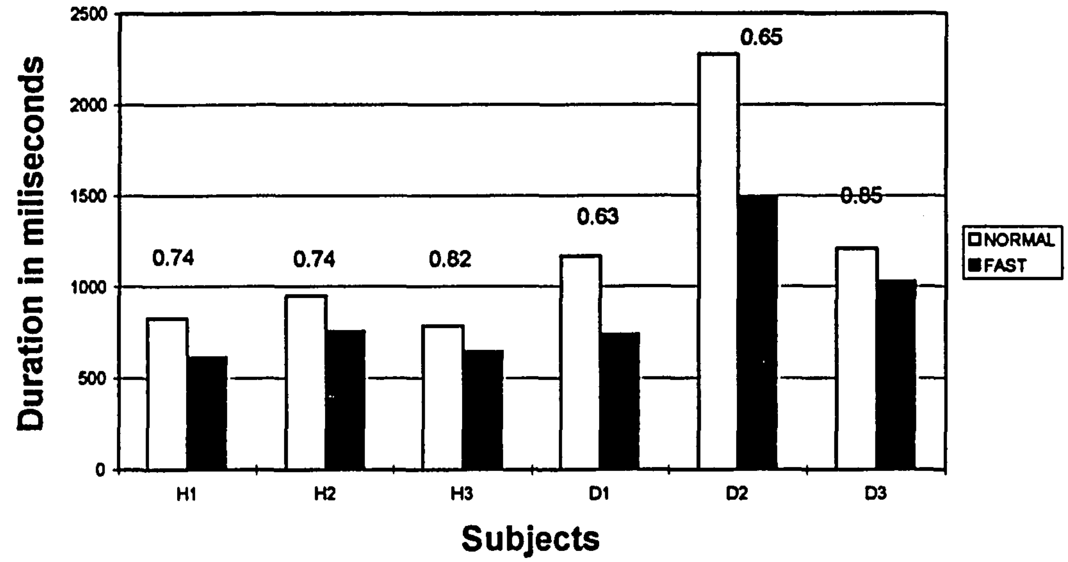


Figure 3.9: Phrase durations (in msec) at normal and fast rate for hearing and deaf talkers.The numerical value on top of the bar pairs indicates the ratio of phrase durations at fast vs. normal rate, i.e. their durational shortening.

Table 3.15: Mean, Standard deviation and Ratio of Durations at Normal and Fast Speaking Rates.
Durations are in milliseconds.

		Phrases		CVC		Schwa		Vowel		Closure		VOT	
		Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast
H1	mean	825	614	236	160	60	45	172	106	87	71	12	7
	stdev	41	23	25	17	15	11	28	18	9	8	7	5
	ratio	0.74		0.68		0.75		0.62		0.81		0.63	
H2	mean	1022	756	303	217	52	31	226	160	112	81	10	4
	stdev	76	52	36	18	13	13	42	17	15	9	8	4
	ratio	0.74		0.71		0.60		0.71		0.73		0.43	
H3	mean	783	644	223	167	47	32	161	114	85	61	12	11
	stdev	29	45	21	17	15	11	22	20	8	10	5	5
	ratio	0.82		0.75		0.68		0.71		0.72		0.89	
D1	mean	1167	741	336	180	132	72	244	123	74	63	13	11
	stdev	100	53	47	19	27	19	5	21	13	12	5	21
	ratio	0.63		0.53		0.54		0.51		0.85		0.86	
D2	mean	2277	1488	792	486	270	121	448	292	228	154	39	40
	stdev	166	106	71	78	73	88	51	52	43	28	31	26
	ratio	0.65		0.61		0.45		0.65		0.67		1.01	
D3	mean	1208	1031	366	310	133	101	216	180	104	94	8	7
	stdev	88	48	35	43	18	15	29	26	12	12	7	4
	ratio	0.85		0.85		0.76		0.83		0.90		0.81	

3.3.2. Coarticulation of disyllables as a function of rate

The purpose of this section is to examine the effects of speaking rate on coarticulatory patterns of hearing and deaf talkers. Coarticulation of both vowel and consonant context is examined. Two aspects of coarticulation are addressed point as a function of rate: a) the spectral changes that occur at a given measurement point b) the point in the schwa syllable at which there are significant differences depending on context.

By definition, the greater the F2 separation between contrastive disyllables at a particular measurement point the greater the coarticulation at that point. For every measurement point, the second formant values in contrastive disyllables were subtracted to yield a single F2 measure: the mean F2 difference. In disyllable pairs contrasting in vowel context, the second member was subtracted from the first. In disyllable pairs contrasted in consonant context, the bilabial member was subtracted from the alveolar member. The direction of F2 difference was indicated by a positive (+) or negative (-) sign. The F2 differences were compared at normal vs. fast rate.

The statistical significance of spectral changes as a function of rate is drawn from planned comparisons of F2 means of disyllables in a pair at normal vs. fast rate (Appendix D). The statistical significance of temporal changes is drawn from planned comparisons of F2 means of disyllable pairs at normal and then at fast rates (Appendix D). All the sets of planned comparisons are computed from six 2x2x3 MANOVAS, for each subject separately.

Sections 3.3.2.1-3.3.2.2 examine the spectral and temporal differences in coarticulation of schwa (/ə/) conditioned by the stressed vowel as a function of rate, in disyllables uttered by the hearing and the deaf talkers. Sections 3.3.2.3-3.3.2.4 examine the spectral and temporal differences in coarticulation of vowels conditioned by consonant context as a function of rate, in disyllables uttered by the hearing and the deaf talkers.

3.3.2.1 Coarticulation of the stressed vowel in disyllables as a function of rate: Hearing and deaf talkers.

3.3.2.1.1 Spectral changes as a function of rate.

The research question addressed is: Does coarticulation of vowel context by hearing and deaf speakers increase with increases in speaking rate?

This research question is examined in relation to the spectral changes at each measurement point as a function of rate. By definition, coarticulation increases at fast rate when the F2 difference, at a given measurement point, is greater at fast than normal rate in the expected direction.

Tables 3.16 and 3.17 present the F2 differences between contrastive disyllables for the hearing and the deaf talkers respectively. Each table shows the F2 differences at each measurement point, rate, and consonant environment and for each talker. Each column shows data for all disyllable pairs, across talkers, at a single measurement point. Each row shows data for a single talker and disyllable pair across rates and measurement points.

These data are plotted in Figures 3.10-3.13, where the mean F2 difference between disyllable pairs at normal and fast rates is examined in relation to measurement position. In each figure, the measurement position is represented on the abscissa and the F2 difference is represented on the ordinate. On the horizontal plane, data are viewed for a single disyllable comparison across talkers. On the vertical plane, data are viewed for all three disyllable comparisons of a single talker. Figures 3.10 and 3.11 show data for the hearing talkers only, for bilabial and alveolar disyllables, respectively. Figures 3.12 and 3.13 show data for the deaf talkers only, for bilabial and alveolar disyllables, respectively.

Table 3.16: Mean F2 differences of disyllable pairs contrasting in vowel context in the hearing talkers at normal and fast rates. Data is shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The second member of the disyllable pair is subtracted from the first.

Disyllables	**Hearing talkers**	Normal rate					Fast rate				
		∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
bib-bub	**H1**	51	82	105	973	1273	94	107	183	967	1224
	H2	110	112	79	903	1138	195	220	223	825	988
	H3	89	67	118	768	1070	200	161	137	740	950
bib-bab		55	86	108	808	1039	89	117	157	811	958
		128	112	82	959	1009	269	277	234	958	968
		100	95	139	748	890	195	192	158	729	833
bab-bub		-11	-24	-4	158	241	-10	-23	22	164	261
		-17	0	-3	-56	129	-75	-58	-11	-133	19
		-11	-28	-21	21	180	5	-32	-21	12	116
did-dud		26	32	13	286	889	49	42	30	248	667
		124	108	58	261	757	59	79	60	228	548
		19	29	34	165	517	85	31	60	155	496
did-dad		19	11	-2	416	1037	17	24	74	424	936
		105	116	95	468	977	81	102	122	446	850
		36	82	97	382	846	124	126	129	357	786
dad-dud		8	21	15	-115	-174	26	9	-38	-181	-261
		18	-8	-36	-206	-220	-12	-20	-46	-237	-311
		-17	-53	-63	-218	-329	-39	-95	-70	-202	-290

Table 3.17: Mean F2 differences of disyllable pairs contrasting in vowel context in the deaf talkers at normal and fast rates. Data is shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The second member of the disyllable pair is subtracted from the first.

Disyllables	Deaf talkers	Normal rate					Fast rate				
		∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
bib-bub	**D1**	32	15	32	55	182	70	122	94	139	158
	D2	-11	3	106	282	426	53	65	27	278	481
	D3	-1	-18	-44	511	847	-22	-26	-108	510	811
bib-bab		60	104	136	438	623	91	164	139	456	485
		-10	33	78	676	483	91	87	7	445	406
		1	51	104	189	228	11	28	72	161	239
bab-bub		-28	-89	-105	-383	-441	-22	-42	-45	-317	-327
		-1	-30	28	-394	-57	-38	-22	20	-167	75
		-2	-69	-148	322	620	-34	-54	-181	349	572
did-dud		54	54	49	53	296	84	142	13	68	414
		-17	42	80	309	616	11	72	92	310	543
		117	108	156	292	838	117	87	75	316	853
did-dad		87	105	136	234	527	104	166	107	160	413
		20	93	-14	198	458	65	32	-20	107	252
		138	110	113	207	229	121	97	64	233	286
dad-dud		-32	-51	-87	-181	-231	-20	-24	-94	-92	1
		-37	-51	94	111	159	-54	39	112	203	292
		-21	-3	43	84	609	-4	-11	11	82	566

3.3.2.1.1.1 The hearing talkers -- Bilabial context

The top half of Table 3.16 presents the F2 differences of bilabial disyllables contrasting in vowel context at normal and fast rate. The F2 differences as a function of rate are shown in Figure 3.10 for bilabial disyllables contrasting in vowel environment. The stars in Figure 3.10 indicate the measurement points at which the spectral changes as a function of rate are statistically significant (see also Appendix D). An inspection of Figure 3.10 reveals the following:

1. During schwa, in bilabial disyllables with front vs. back vowel contexts (top and middle panels), two hearing talkers (H2 and H3) show greater F2 differences at fast than normal rate. The increases in anticipatory coarticulation as a function of rate are greater for the /∂bib/-/∂bab/ than for the /∂bib/-/∂bub/ pair, across two talkers (H2 and H3). In low back vs. high back vowel contexts (bottom panel of Fig. 3.10), the hearing talkers show no significant differences between fast and normal rate. Talker H2, however, shows a tendency for greater F2 differences at fast rate.

2. Within the stressed syllable, the hearing talkers show instances of decreased F2 differences at fast rate, particularly at vowel midpoint.

An account of result #2 is provided by an examination of each disyllable in tables 3.3-3.5 of section 3.2. The result is attributed to context-specific changes as a function of rate induced by neutralization of, primarily, high vowel centers [i] and [u].

3.3.2.1.1.2 The hearing talkers -- Alveolar context.

The bottom half of Table 3.16 presents the F2 differences of bilabial disyllables contrasting in vowel context at normal and fast rate. The F2 differences as a function of rate are shown in Figure 3.11 for alveolar disyllables contrasting in vowel environment. The stars in Figure 3.11 indicate significant spectral changes as a function of rate (see also Appendix D). An inspection of Figure 3.11 reveals the following:

1. Overall, during schwa, the F2 difference between contrasting disyllables was no greater at fast than normal rates. The hearing talkers, overall, did not show coarticulatory increases in alveolar disyllables at fast rate. Sporadic cases, where coarticulatory increases occurred, were noted in the /ədid/-/ədad/ comparison (middle panel).

2. At the vowel midpoint of the stressed syllable, in most cases, the F2 difference between contrastive disyllables was smaller at fast than normal rate. This pattern occurred primarily for disyllables with front/back vowel contrasts.

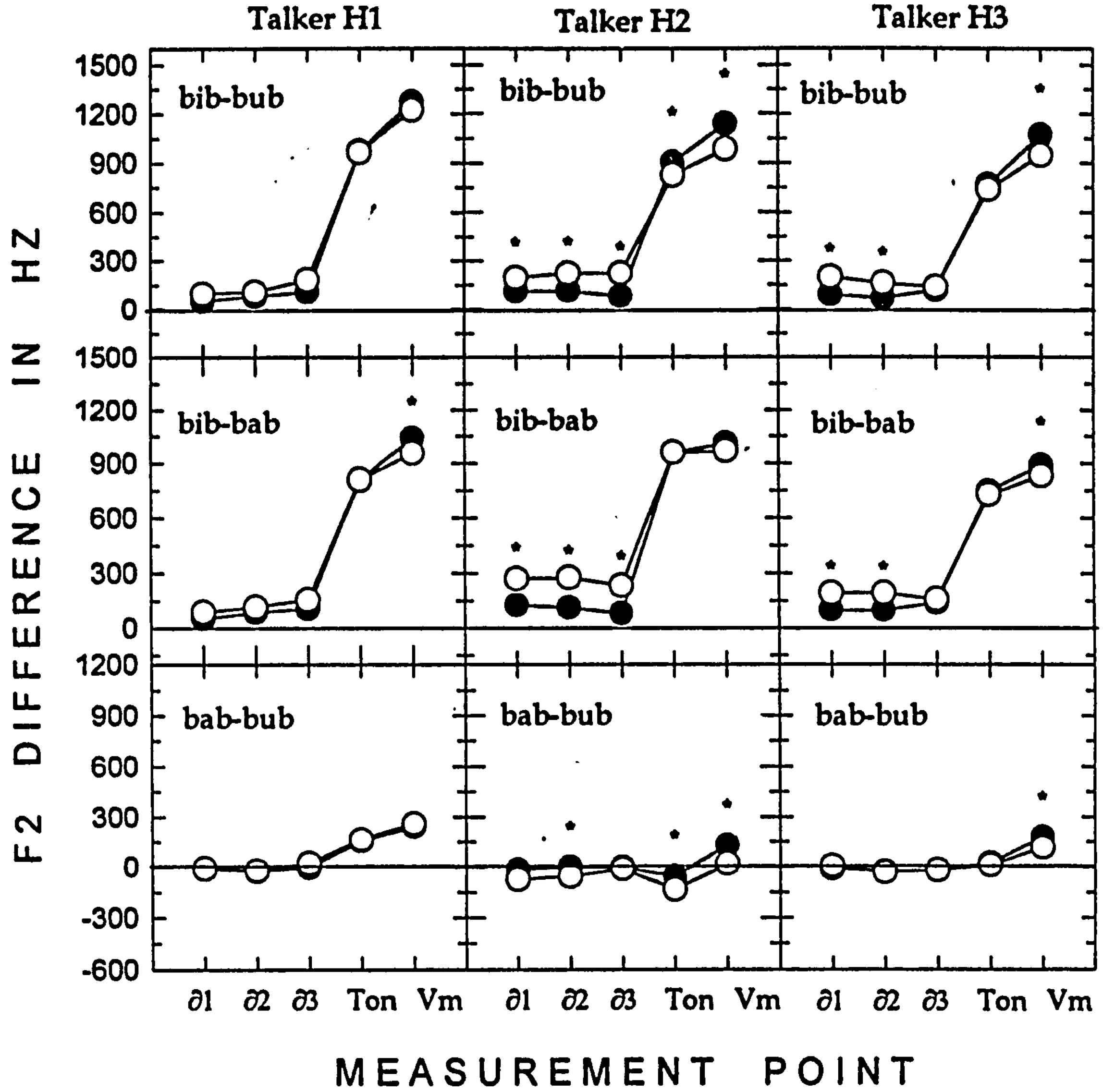
The result #2 is attributed to the uneven, context-specific F2 changes of disyllables as a function of rate (see Tables 3.3-3.5 of section 3.2). These changes are talker-specific, e.g. neutralization of [i] center at fast rate (talker H2) and/or increased coarticulation of back vowel centers, [u] or [a], with alveolar context.

3.3.2.1.1.3 The deaf talkers -- Bilabial context

The top half of Table 3.17 presents the F2 differences of bilabial disyllables contrasting in vowel context at normal and fast rate. The F2 differences as a function of rate are shown in Figure 3.12 for bilabial disyllables contrasting in vowel environment. The stars in Figure 3.12 indicate significant spectral changes as a function of rate (see also Appendix D). An inspection of Figure 3.12 reveals the following:

1. During schwa, the changes as a function of rate are not significant for the deaf talkers. Sporadic instances of greater F2 differences at fast than normal rate are noted for bilabial disyllables contrasting in front/back vowels (top and middle panels) for two deaf talkers (D1 and D2). This pattern, however, is more frequent in the hearing talkers (section 3.3.2.1.1.1.). In bilabial disyllables contrasting in low back/high back vowel centers (bottom panel), the deaf talkers did not show increased F2 differences at fast rate. This pattern is consistent with the results for the hearing talkers.

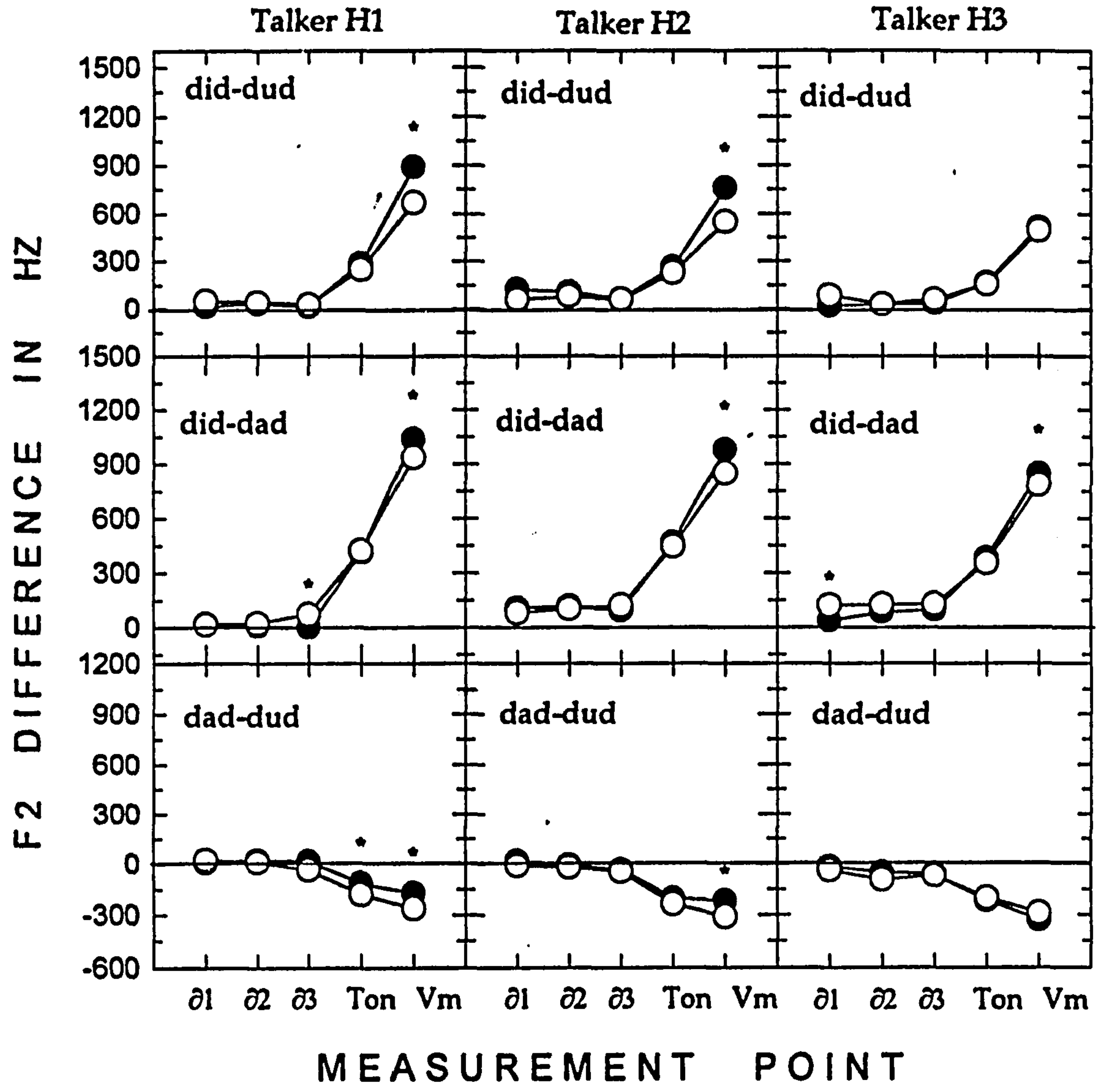
2. Within the stressed syllable, two the deaf talkers, D1 and D2, showed decreased F2 differences at fast compared to normal rates (middle and bottom panels). The pattern is less common in the deaf than the hearing talkers (Fig. 3.12,



ə 1 = schwa onset
ə 2 = schwa midpoint
ə 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

—●— Normal rate
—○— Fast rate

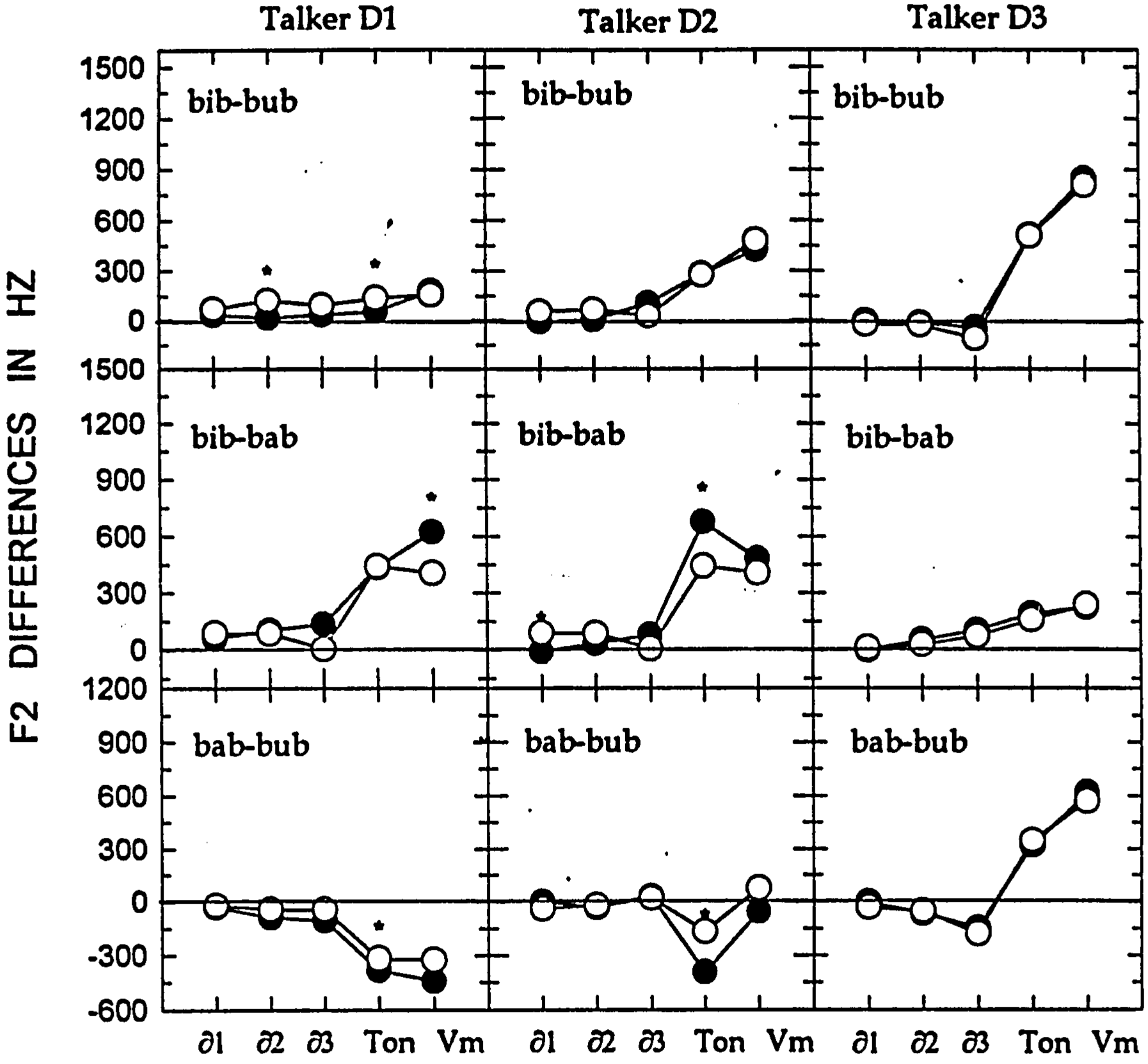
Figure 3.10: F2 differences of bilabial disyllables contrasting in vowel context, at each measurement point, at normal vs. fast rates. Rows show data across hearing talkers. Columns show data across vowel contrasts for a talker. The second member of the disyllable pair is subtracted from the first. The stars indicate that the shifts of F2 differences are significant or approach significance.



ə 1 = schwa onset
ə 2 = schwa midpoint
ə 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

—●— Normal rate
—○— Fast rate

Figure 3.11: F2 differences of alveolar disyllables contrasting in vowel context, at each measurement point, at normal vs. fast rates. Rows show data across hearing talkers. Columns show data across vowel contrasts for a talker. The second member of the disyllable pair is subtracted from the first. The stars indicate that the shifts of F2 differences are significant or approach significance.



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

● Normal rate
○ Fast rate

Figure 3.12: F2 differences of bilabial disyllables contrasting in vowel context, at each measurement point, at normal vs. fast rates. Rows show data across deaf talkers. Columns show data across vowel contrasts for a talker. The second member of the disyllable pair is subtracted from the first. The stars indicate that the shifts of F2 differences are significant or approach significance.

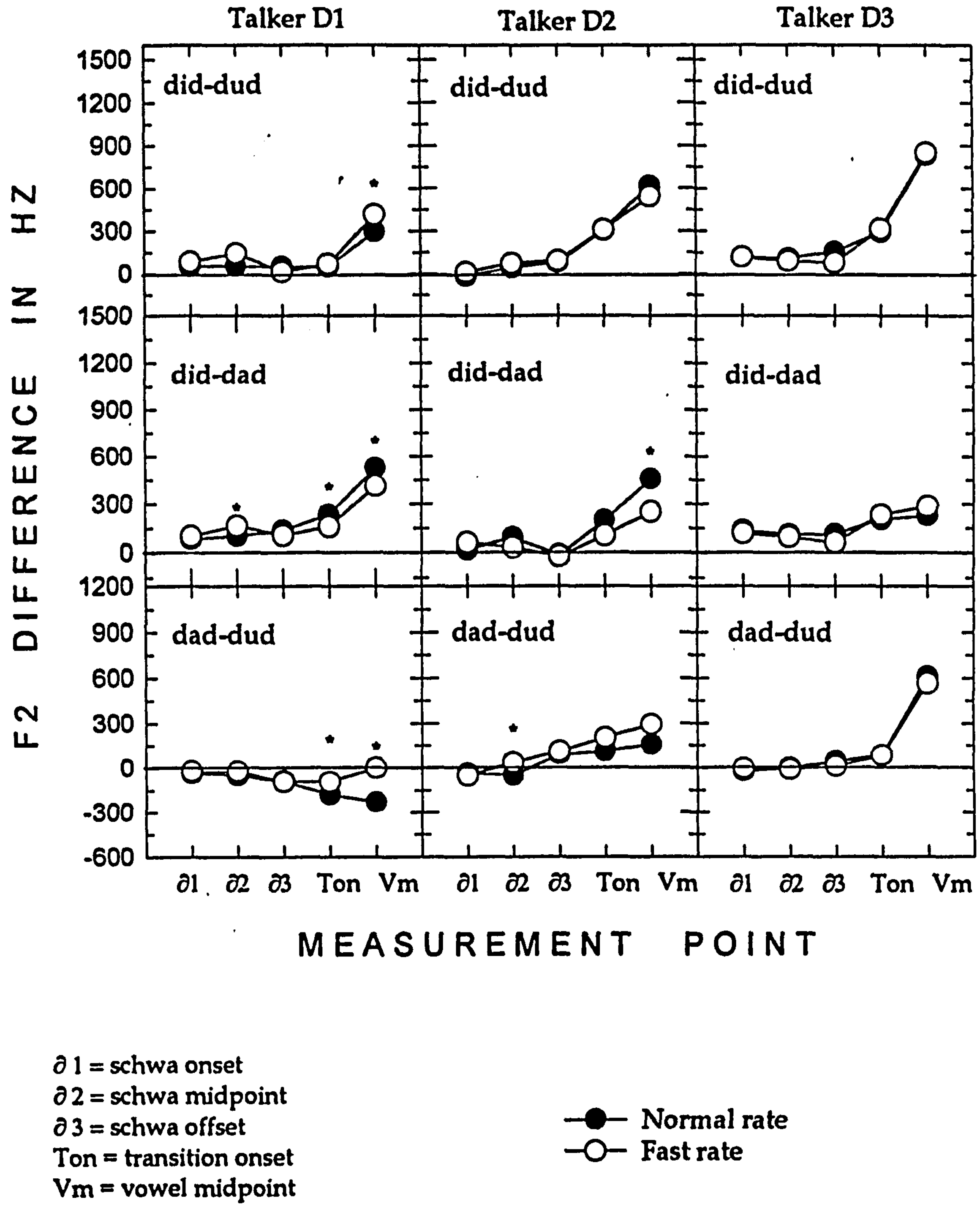


Figure 3.13: F2 differences of alveolar disyllables contrasting in vowel context, at each measurement point, at normal vs. fast rates. Rows show data across deaf talkers. Columns show data across vowel contrasts for a talker. The second member of the disyllable pair is subtracted from the first. The stars indicate that the shifts of F2 differences are significant or approach significance.

section 3.3.2.1.1.1.) Result #2 can be ascribed to neutralization of some vowel centers. An examination of the F2 means of the stressed vowel of each disyllable (Tables 3.3-3.5 of section 3.2) reveals that both the deaf talkers have lower F2 in the high vowel centers [i] and [u] at fast compared to normal rate (note that at normal rate, these two talkers have high F2 values for [u]). Hence, the F2 values in those vowel centers in the fast rate condition are more proximal to F2 for [a] resulting in smaller F2 differences of [i]-[a] and [a]-[u] centers.

3.3.2.1.1.4 The deaf talkers -- Alveolar context

The bottom half of Table 3.17 lists the F2 differences of alveolar disyllables contrasting in vowel context at normal and fast rates. These F2 differences as a function of rate are shown in Figure 3.13. The stars in Figure 3.13 indicate significant spectral changes as a function of rate (see also Appendix D). An inspection of Figure 3.13 reveals the following:

1. During schwa, in general, the deaf talkers did not show increased F2 differences at fast rate. Thus, overall, no anticipatory coarticulation increases are inferred. Some instances, however, are noted in two deaf talkers, D1 (middle left panel) and D2 (bottom center panel).

2. Within the stressed syllable, two deaf talkers show changes in F2 differences as a function of rate in either direction and so coarticulatory changes are inferred. Increased F2 differences were noted for talker D1 (top left panel) at

vowel midpoint. Decreased F2 differences occurred for two the deaf talkers, D1 (middle and bottom panel) and D2 (middle panel). Increased coarticulation is noted for deaf talker D1, a pattern not seen in the hearing talkers.

3. No significant coarticulatory changes were noted in talker D3 as a function of rate.

The decreased F2 differences within the stressed syllable (result #2) are attributed to context-specific neutralization or increased coarticulation of [a] center with alveolar context. An examination of the F2 means for each disyllable at vowel onset and vowel midpoint (Tables 3.6-3.7 of section 3.2) reveals that both talkers, D1 and D2 have lower [i] and higher [a] centers at fast rate. Furthermore, for D2, in the /∂dad/-/∂dud/ pair, F2 is lower for [u] and higher for [a] at fast rate (recall from section 1 that D2 has a high F2 mean for [u] at normal rate).

3.3.2.1.5 Discussion and conclusions

Spectral changes in anticipation of vowel centers were much more frequent in bilabial than alveolar disyllables in the speech of the hearing talkers. This pattern did not occur in the speech of the deaf talkers. Cases of spectral increases in anticipation of vowel centers as a function of rate were comparable in bilabial vs. alveolar environments. These findings indicate that interarticulatory coordination results in greater gestural overlap in the hearing, but not in the deaf talkers.

No changes as a function of rate were noted in anticipation of low back/high back vowel context in bilabial and alveolar disyllables -- except for D2 in /ədad-ədud/. This finding is expected since the [a] and [u] centers differ minimally in their second formant values.

Both the hearing and the deaf talkers showed instances of vowel neutralization within the stressed syllable at fast rate. This pattern occurred for both bilabial and alveolar disyllables and was stronger in the hearing talkers, presumably because of their greater dispersion of vowel centers as compared to the deaf talkers.

3.3.2.1.2 Temporal anticipatory changes as a function of rate.

The research question addressed is:

Do increases in the temporal onset of anticipatory coarticulation occur as a function of increased rate in the speech of hearing and deaf talkers?

The following analysis is based on Tables 3.18 and 3.19 which present the measurement points at which the F2 means of contrasting disyllables were significantly different, for hearing and the deaf talkers respectively. Each table contrasts patterns in alveolar vs. bilabial contexts (vertical dimension) and across speaking rates (horizontal dimension). The cases where patterns approach significance were also included in the tables. The complete set of planned comparisons at each measurement point for each talker at fast rate can be found in

Appendix D. The results are discussed with reference to the temporal onset of anticipatory coarticulation at normal vs. fast rates.

3.3.2.1.2.1. The hearing talkers -- Bilabial context -- top part of Table 3.18,

1. In bilabial disyllables contrasting in front/back vowel centers, the onset of anticipatory coarticulation of vowel context occurred at schwa onset in normal and fast rates for all the hearing talkers, i.e. no change in F2 differences was noted as a function of rate.

2. In bilabial disyllables contrasted in low back/high back vowel centers ([a]/[u]), no substantial temporal changes occurred as a function of rate[18].

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[18] It should be noted that one talker, H2, exhibited different F2 means at an earlier measurement point (schwa onset) of the disyllable contrast at fast rate. However, since his F2 difference diminishes at vowel midpoint, one concludes that this change is not a product of temporal increases in anticipatory coarticulation.

3.3.2.1.2.2 The hearing talkers -- Alveolar context -- bottom part of Table 3.18,

1. In alveolar disyllables contrasted in front/back vowels, two hearing talkers, H1 and H3, showed earlier anticipation of vowel centers with increased rate[19].

2. In alveolar disyllables contrasted in low back/high back vowels, no changes occurred in the temporal extent of vocalic anticipation.

3.3.2.1.2.3. The deaf talkers -- bilabial context -- top part of Table 3.19,

1. In bilabial disyllables contrasted in front/back vowel centers, the deaf talkers showed instances of increased or decreased temporal anticipation of vowel centers with increased rate. Such patterns were context- and talker-specific. The decreased temporal anticipation of vowel centers is attributed to vowel-specific neutralization.

2. In bilabial disyllables contrasted in low back/high back vowel centers, the deaf talkers showed instances of increased or decreased temporal anticipation of vowel centers with increased rate. Talker D1 showed decreased temporal

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[19] Nevertheless, in /∂did-∂dud/, the F2 means for these talkers did not differ at schwa midpoint and schwa offset as a function of rate. Examination of F2 means for each disyllable in Tables 3.6 and 3.8 of section 3.2 indicate higher F2 means in /∂dud/ but not in /∂did/ at schwa midpoint and schwa offset as a function of rate, mainly because of anticipation of alveolar context.

anticipation because of neutralization of [u] center at fast rate (D1's F2 at the vowel midpoint of /ǝbub/ is particularly high at normal rate -- see Table 3.9 in section 3.2). Talker D3 shows increased temporal anticipation.

3.3.2.1.2.4 The deaf talkers -- Alveolar context -- bottom part of Table 3.19,

1. In alveolar disyllables contrasting in front/back vowels, one deaf talker, D2, exhibited earlier anticipation of vowel centers with increased rate[20]. Note that the other the deaf talkers showed early onset of anticipatory coarticulation at both normal and fast rates.

2. In alveolar disyllables contrasting in low back/high back vowels, one deaf talker, D1, exhibited decreased temporal anticipation of vowel centers at fast rate. The pattern is attributed to uneven F2 changes in members of the disyllable pair, higher F2 in /ǝdad/ and lower F2 in /ǝdud/ from normal to fast rate.

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[20] In /ǝdid/-/ǝdad/ pair, talker D2 showed different F2 means at schwa onset at fast rate. Note, however, that at fast rate, the F2 means did not differ at later stages in the schwa nor at transition onset. An examination of F2 means in Table 3.10 of section 3.2 shows a higher F2 in /ǝdad/ but not in /ǝdid/ at fast rate. This uneven F2 rise may be attributed to influences of the alveolar environment or, alternatively, neutralization of [i] at fast rate, or both factors.

3.3.2.1.2.5 Discussion and conclusions

In bilabial disyllables, no changes in the temporal onset of anticipatory coarticulation of vowel context occurred in the hearing talkers. Significant patterns were noted as early as schwa onset at both rates (a ceiling effect). In alveolar disyllables, D1 and D3 showed early temporal onset at both rates (a ceiling effect).

In bilabial disyllables, unsystematic changes in the temporal onset of anticipatory coarticulation of vowel context were observed in the deaf talkers. Temporal onset increased or decreased in a talker-specific and contrast-specific manner.

In alveolar disyllables, both the hearing and the deaf talkers exhibited earlier anticipation of front/back vowel centers as a result of increased rate. The pattern was stronger in the hearing talkers because the deaf talkers systematically showed early temporal onset (at schwa onset) at both rates.

Earlier onset of anticipatory coarticulation at fast rate was not observed in disyllable pairs with low back/high back vowels across talkers and consonant contexts, except for one deaf speaker, D3.

A later onset of anticipatory coarticulation of vowel centers occurred on several occasions for deaf but not for the hearing talkers. The pattern was observed in bilabial and alveolar contexts and is attributed to disproportionate F2 differences between the members of the disyllable pair as a function of rate. These most likely result from coarticulatory influences of consonant context, or alternatively, from selective neutralization of vowel centers.

Table 3.18: Anticipatory coarticulation of vowel context in bilabial and alveolar disyllables by the hearing talkers at normal vs. fast rates. Planned comparisons of F2 means of contrasting disyllables are shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level.

		NORMAL RATE					FAST RATE				
Subjects	Disyllables	∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
H1	/bib/-/bab/	*.0491	*	*	*	*	*	*	*	*	*
H2	/bib/-/bab/	*	*	*	*	*	*	*	*	*	*
H3	/bib/-/bab/	*	*	*	*	*	*	*	*	*	*
	/bib/-/bub/	*.0097	*	*	*	*	*	*	*	*	*
	/bib/-/bub/	*	*	*	*	*	*	*	*	*	*
	/bib/-/bub/	*.0054	*.0114	*	*	*	*	*	*	*	*
	/bab/-/bub/				*	*				*	*
	/bab/-/bub/					*	*.0135	*.0141		*	
	/bab/-/bub/					*					*
	/did/-/dad/				*	*			*.0085	*	*
	/did/-/dad/	*	*	*	*	*	*.0252	*	*	*	*
	/did/-/dad/		*	*	*	*	*	*	*	*	*
	/did/-/dud/				*	*	*.0387			*	*
	/did/-/dud/	*	*	*.0248	*	*	*.0502	*	*.046	*	*
	/did/-/dud/				*	*	*.007			*	*
	/dad/-/dud/				*	*				*	*
	/dad/-/dud/				*	*				*	*
	/dad/-/dud/		*.0420	*.0160	*	*		*	*.059	*	*

Table 3.19: Anticipatory coarticulation of vowel context in bilabial and alveolar disyllables by the deaf talkers at normal vs. fast rates. Planned comparisons of F2 means of contrastive disyllables are shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level.

NORMAL RATE							FAST RATE				
Subjects	Disyllables	∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
D1	/bib/-/bab/	*	*	*	*	*	*	*	*	*	*
D2	/bib/-/bab/			*.0445	*	*	*.009	*.019		*	*
D3	/bib/-/bab/			*.0053	*	*				*	*
	/bib/-/bub/				*.0225	*	*	*	*.009		*
	/bib/-/bub/			*.0072	*	*				*	*
	/bib/-/bub/				*	*			*.0069	*	*
	/bab/-/bub/		*	*.0090	*	*				*	*
	/bab/-/bub/				*					*.0053	
	/bab/-/bub/				*	*			*	*	*
	/did/-/dad/	*	*	*	*	*	*	*	*	*	*
	/did/-/dad/		*.0097		*	*	*.059				*
	/did/-/dad/	*	*	*	*	*	*	*		*	*
	/did/-/dud/	*.0065	*.0189		*.0282	*	*	*		*.0282	*
	/did/-/dud/			*.041	*	*		*.954	*.0297	*	*
	/did/-/dud/	*	*	*	*	*	*	*.008	*.0584	*	*
	/dad/-/dud/	*.0464	*.0252	*.0287	*	*			*.0101	*	
	/dad/-/dud/			*.0170	*.0362	*			*.008	*	*
	/dad/-/dud/				*.0517	*					*

3.3.2.2 Coarticulation of vowels conditioned by consonant context in disyllables as a function of rate: Hearing and deaf talkers.

The research question addressed is: Does coarticulation of vowels conditioned by consonant context increases with increases in speaking rate for hearing and deaf speakers?

This research question is examined in this section in relation to the spectral changes at each measurement point as a function of rate. It is assumed that coarticulation increases at fast rate when the F2 difference, at a given measurement point, is greater at fast than at normal rate.

Table 3.20 presents the F2 differences between contrastive disyllables for the hearing and the deaf talkers. The table shows the F2 differences at each measurement point, rate, consonant environment, and for each talker. Each column shows data for all disyllable pairs, across talkers, at a single measurement point. Each row shows data for a single talker and disyllable pair across rates and measurement points.

These data are plotted in figures 3.14-3.15, where the mean F2 difference of disyllable pairs at normal and fast rates is examined in relation to measurement position. In each figure, the measurement position is plotted on the abscissa and the F2 difference is plotted on the ordinate. Rows contain data for a single disyllable comparison across talkers. Columns contain data for all three disyllable comparisons of a single talker. Figure 3.14 shows data for the hearing talkers only.

Figure 3.15 shows data for the deaf talkers only. In each figure, the stars indicate that the F2 means of contrasting disyllables were significantly different at normal vs. fast rates as revealed by planned comparisons of 2x2x3 MANOVAS (Appendix D).

Table 3.20: Mean F2 differences of disyllable pairs contrasting in consonant context in the hearing and the deaf talkers, at normal and fast rates. Data is shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The bilabial member of the disyllable pair is subtracted from the alveolar member.

Disyllables	Talkers	Normal rate					Fast rate				
		∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
bib/did	**H1**	55	86	108	808	1039	89	117	157	811	958
	H2	194	321	489	25	19	159	231	326	-11	-7
	H3	214	323	362	53	4	239	303	358	92	50
bub/dud		-11	-24	-4	158	241	-10	-23	22	164	261
		195	331	509	667	400	295	372	488	586	432
		266	352	438	657	557	331	415	421	688	508
bab/dad		51	82	105	973	1273	94	107	183	967	1224
		217	324	471	516	50	353	411	449	503	119
		262	327	399	419	48	284	339	355	463	97
bib/did	**D1**	-14	-9	204	19	-54	-19	30	175	-30	-20
	D2	0	118	304	-160	-4	-4	82	385	56	-87
	D3	150	184	352	241	39	141	168	276	261	98
bub/dud		-35	-36	188	21	-168	-33	20	256	40	-227
		10	70	312	-187	-225	13	75	295	24	-150
		9	54	149	461	49	2	55	92	514	56
bab/dad		-36	2	199	223	42	-32	38	208	265	53
		-29	50	370	317	-8	22	137	412	394	67
		-17	120	338	223	38	32	99	284	188	51

3.3.2.2.1 Spectral changes as a function of rate.

3.3.2.2.1.1. The hearing talkers

The F2 differences as a function of rate are shown in Figure 3.14. The stars in this figure indicate the measurement points at which the spectral changes as a function of rate are significant. An inspection of Figure 3.14 reveals the following:

1. During schwa, in general, the hearing talkers did not exhibit spectral changes as a function of rate. However, one hearing talker, H2, shows increased or decreased F2 differences among contrastive disyllables at fast rate in a vowel-specific manner[21].

2. Within the stressed syllable, the magnitude of F2 differences changes in either direction, i.e. these are asystematic differences in coarticulation as a function of rate for all the hearing talkers.

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[21] Note that in H2's schwa, increased F2 differences are noted for disyllables containing back vowels. Decreased F2 differences are noted for disyllables containing [i], presumably due to neutralization of [i] at fast rate.

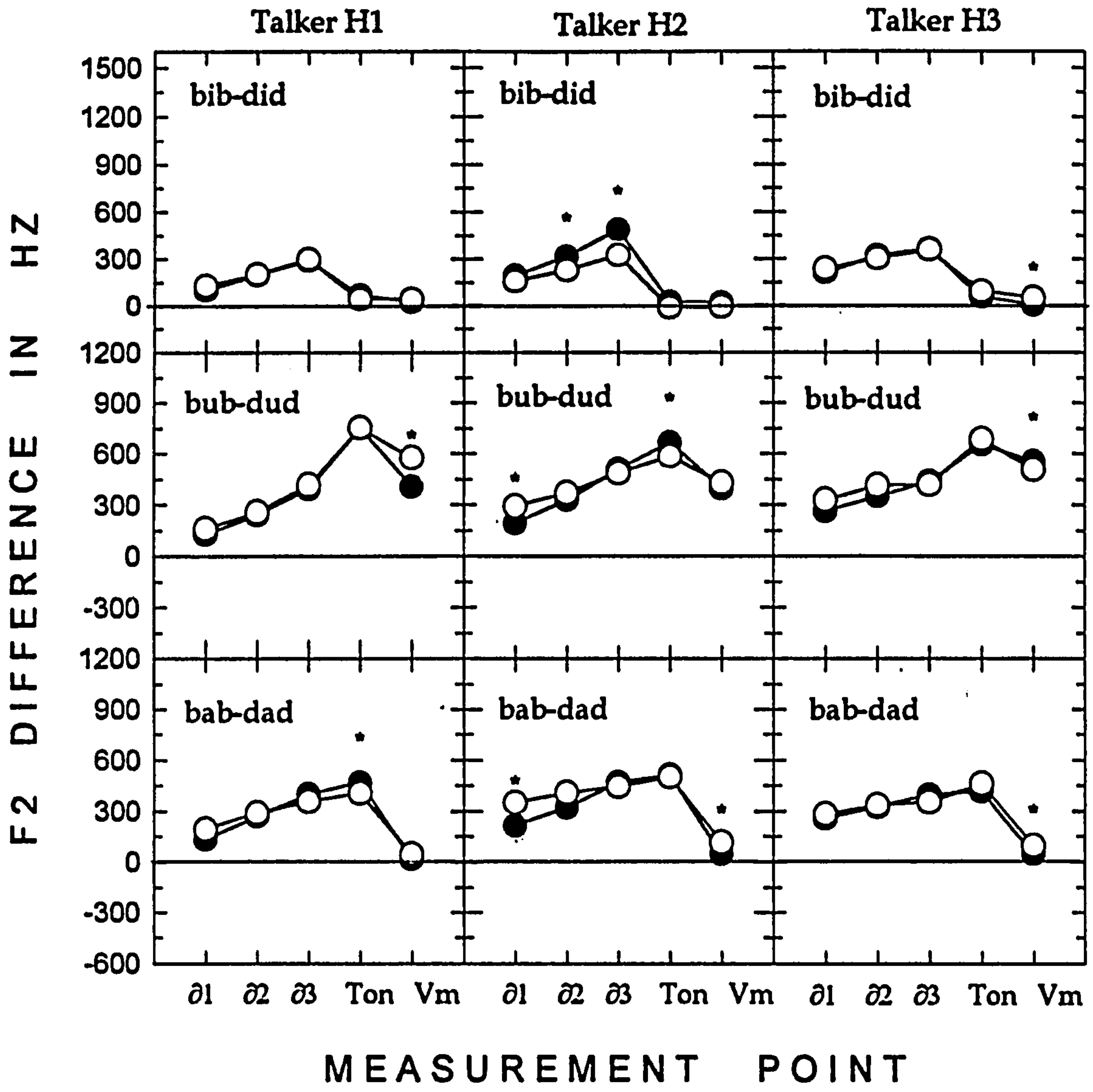
3.3.2.2.1.2. The deaf talkers

The F2 differences as a function of rate are shown in Figure 3.15. An inspection of Figure 3.15 reveals the following:

1. During schwa, the deaf talkers did not often show changes in F2 differences. One infers no differences in coarticulation of consonant context as a function of rate. An exception was noted for talker D2 in /əbab/-/ədad/ where the F2 difference increased at fast rate at schwa midpoint.

2. Within the stressed syllable, two talkers, D1 and D2, show increased F2 differences at fast rate. The pattern was observed at talker-specific contexts and measurement locations.

3. Talker D3 did not exhibit changes of F2 differences as a function of rate.



∂ 1 = schwa onset
∂ 2 = schwa midpoint
∂ 3 = schwa offset
Ton = transition onset
Vm = vowel midpoint

—●— Normal rate
—○— Fast rate

Figure 3.14: F2 differences of disyllables contrasting in consonant context, at each measurement point, at normal vs. fast rates. Rows show data across hearing talkers. Columns show data across vowel contrasts for a talker. The bilabial member of the disyllable pair is subtracted from the alveolar one. The stars indicate that the shifts of F2 differences are significant or approach significance.

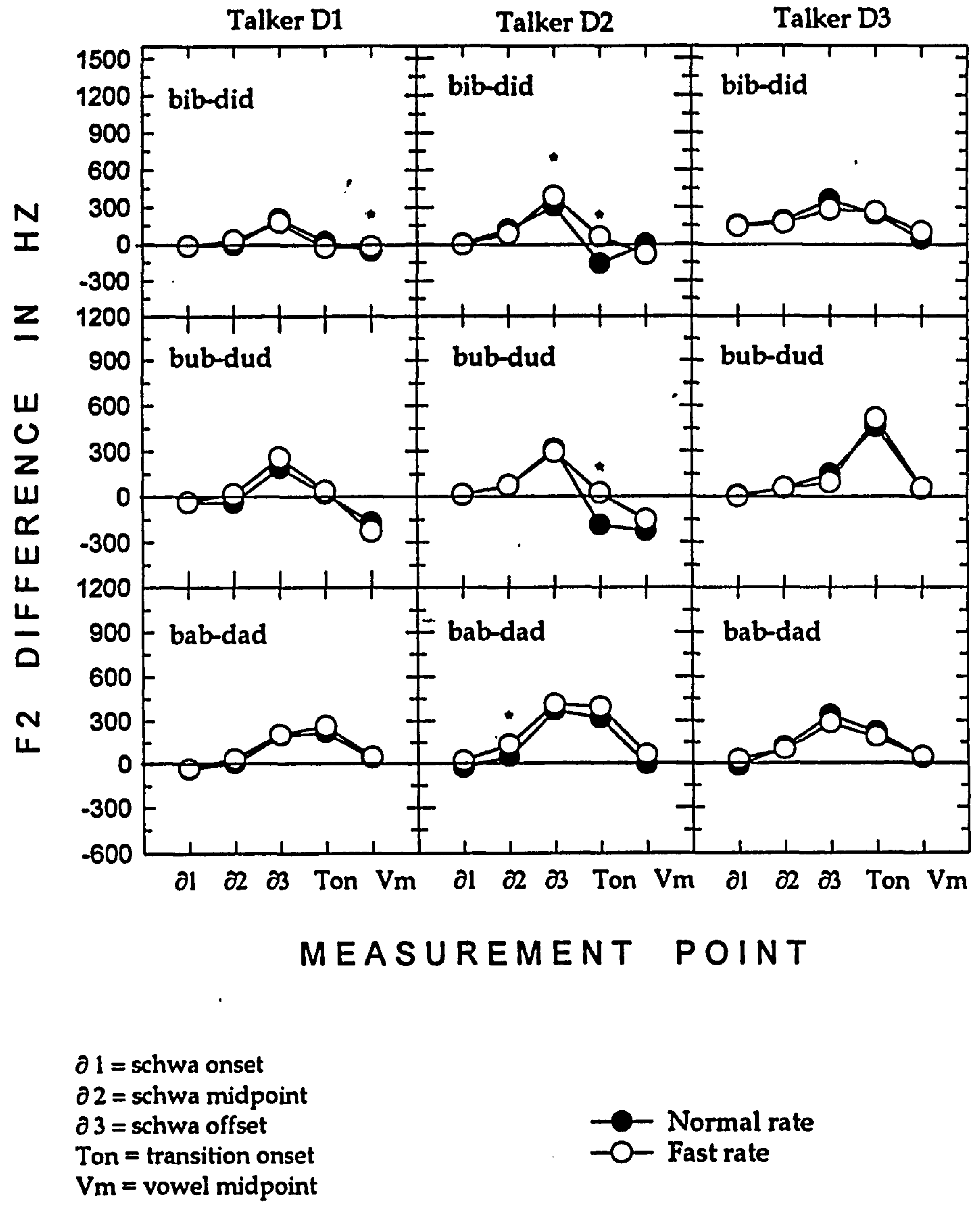


Figure 3.15: F2 differences of disyllables contrasting in consonant context, at each measurement point, at normal vs. fast rates. Rows show data across deaf talkers. Columns show data across vowel contrasts for a talker. The bilabial member of the disyllable pair is subtracted from the alveolar one. The stars indicate that the shifts of F2 differences are significant or approach significance.

3.3.2.2.1.3 Discussion and conclusions

Both the hearing and the deaf talkers showed very few instances of increased coarticulation of consonant context as a function of rate. The number of cases is roughly comparable across groups.

The hearing talkers, however, exhibited cases of decreased F2 differences at fast rates, during schwa or within the stressed syllable, a pattern not observed in the deaf talkers. The finding of decreased coarticulation of consonant context as a function of rate, revealed in the hearing talkers, is unexpected and is attributed to unequal spectral differences, as a function of rate, in the members of the disyllable pair. These differences can be caused by unequal neutralization of vowel centers in bilabial vs. alveolar environments with increased rate.

3.3.2.2.2 Temporal anticipatory changes as a function of rate.

The research question is: Do increases in the temporal onset of anticipatory coarticulation of consonant context occur as a function of rate in the speech of hearing and deaf talkers?

The following analysis is based on Table 3.21 which presents the measurement points at which the F2 means of contrasting disyllables were significantly different. The table compares talkers across hearing status (vertical dimension) and across speaking rates (horizontal dimension). The cases where patterns approach significance were also included in the tables. The complete set of planned comparisons at each measurement point for each talker at fast rate can be found in Appendix D. The results are discussed with reference to the temporal onset of anticipatory coarticulation at normal vs. fast rates.

3.3.2.2.2.1 The hearing talkers

As seen in Table 3.21,

1. The hearing talkers exhibited no temporal changes in anticipatory coarticulation of consonant context as a function of rate. In both rates, there was a ceiling effect, namely, significantly different F2 means occurred at schwa onset.

2. Within the stressed syllable, for some disyllable pairs in one talker, H3, coarticulation of consonant context extends to the vowel midpoint.

3.3.2.2.2.2. The deaf talkers

As seen in Table 3.21, the deaf talkers exhibited very few differences in temporal onset of coarticulation of consonant context as a function of rate. Differences were asystematic., i.e. direction was talker-specific.

Note that in D2, abnormal coarticulatory patterns decrease with increased rate. The F2 means of /əbib/ were higher than /ədid/ at normal but not at fast rate.

3.3.2.2.2.3 Discussion and conclusions

Overall, neither the hearing nor the deaf talkers show systematic changes in the temporal onset of coarticulation of consonant context with rate.

Table 3.21: Coarticulation of consonant context in disyllables as a function of rate. Data from both the hearing and the deaf talkers. Planned comparisons of F2 means for contrastive disyllables are shown at five measurement points for each rate, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level.

		Normal rate					Fast rate				
disyllables	hearing	∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
/bib/-/did/	H1	*	*	*	*		*	*	*	.0587	
/bib/-/did/	H2	*	*	*			*	*	*		
/bib/-/did/	H3	*	*	*			*	*	*	*	*.009
/bub/-/dud/	H1	*	*	*	*	*	*	*	*	*	*
/bub/-/dud/	H2	*	*	*	*	*	*	*	*	*	*
/bub/-/dud/	H3	*	*	*	*	*	*	*	*	*	*
/bab/-/dad/	H1	*	*	*	*		*	*	*	*	
/bab/-/dad/	H2	*	*	*	*	*.0219	*	*	*	*	*
/bab/-/dad/	H3	*	*	*	*		*	*	*	*	*
disyllables	deaf	∂1	∂2	∂3	Ton	Vm	∂1	∂2	∂3	Ton	Vm
/bib/-/did/	D1			*					*		
/bib/-/did/	D2		*	*	*			*.0281	*		
/bib/-/did/	D3	*	*	*	*		*	*	*	*	
/bub/-/dud/	D1			*		*			*		*
/bub/-/dud/	D2		*.0476	*	*	*		*.0431	*	*	*.018
/bub/-/dud/	D3			*	*	*0517			*.0216	*	
/bab/-/dad/	D1	*.0464		*	*				*	*	
/bab/-/dad/	D2			*	*			*	*	*	
/bab/-/dad/	D3		*	*	*			*	*	*	

3.4. COMPARISON OF COARTICULATION IN DISYLLABLES ACROSS SUBJECTS AT COMPARABLE DURATIONS

The research question addressed is: Do the coarticulatory patterns of deaf talkers resemble those of hearing talkers at comparable durations?

The comparable durations across the two groups were derived by comparing the mean duration of all utterances at normal rate for the hearing talkers with the mean duration of all utterances at fast rate for the deaf talkers. Table 3.15 in section 3.3.1. lists the mean durational values of various utterance parts at normal and fast rate for each talker, averaged across consonant and vowel type. Several points are worth discussing here with respect to the comparable durations in the hearing vs. the deaf talkers:

a) The durations of the stressed syllable at fast rate for deaf talker D3 were like those of the stressed syllable at normal rates for the hearing talkers.

b) The productions of talker D2 at fast rate were still longer (by roughly 100-150 msec) than the productions of the hearing talkers at normal rate.

c) The productions of talker D1 at normal and fast rate fell slightly below and above the productions of the hearing talkers at normal rate.

d) The schwa durations of the deaf talkers at fast rate were longer than the schwa durations of the hearing talkers at normal rate (but shorter than the stressed vowel durations of the hearing talkers). Since the deaf talkers had longer durations in the unstressed parts of the disyllables anticipatory effects of the stressed syllable might be expected to be greater in the hearing group on this basis alone. Namely, at comparable durations, according to the coproduction account (Fowler, 1980; Bell-Berti & Harris, 1981; Browman & Goldstein 1986) the intersegmental overlap is greater when the unstressed segment has a shorter duration.

3.4.1 Coarticulation at comparable durations

3.4.1.1 Coarticulation of vowel context at comparable durations.

The significant patterns of F2 mean differences in disyllable pairs of identical consonant environment and contrastive vowel centers were compared across subjects at comparable durations.

Table 3.22 presents the above F2 means at comparable durations across subjects, i.e. at normal rate for the hearing talkers and at fast rate for the deaf talkers.

In cross-group comparisons at comparable rates (Table 3.22) one observes the following general trends:

1. In bilabial disyllables with front vs. back vowel contrasts, the hearing talkers exhibited earlier anticipation of the stressed vowel than the deaf talkers.

2. In alveolar disyllables with front vs. back vowel contrasts, the deaf talkers exhibited earlier anticipation of the stressed vowel than the hearing talkers.

3. In bilabial disyllables contrasted in back, high/low vowels, the deaf talkers exhibited earlier extent of anticipation than the hearing talkers.

4. A clear pattern of differences did not emerge in alveolar disyllables contrasted in back, high/low vowels with respect to cross group comparisons. Two the deaf talkers showed anticipation of vowel context at schwa offset as opposed to transition onset for two the hearing talkers. One hearing talker showed effects at schwa midpoint.

Figures 3.16 and 3.17 compare the F2 differences of disyllables with contrasting vowel context as they appear for each deaf talker with respect to the hearing talkers at comparable durations during the schwa. Figure 3.16 compares F2 differences in bilabial disyllables. Figure 3.17 compares F2 differences in alveolar disyllables. Data across the deaf talkers are plotted horizontally. Data across disyllable pairs are plotted vertically.

An inspection of Figures 3.16 and 3.17 indicates a pattern similar to normal rate for deaf vs. the hearing talkers at comparable rates, i.e. the anticipatory coarticulation tends to be greater in the hearing group in bilabial disyllables with front/back vowel contrasts but in alveolar disyllables the phenomenon is noted for the deaf talkers more than the hearing talkers.

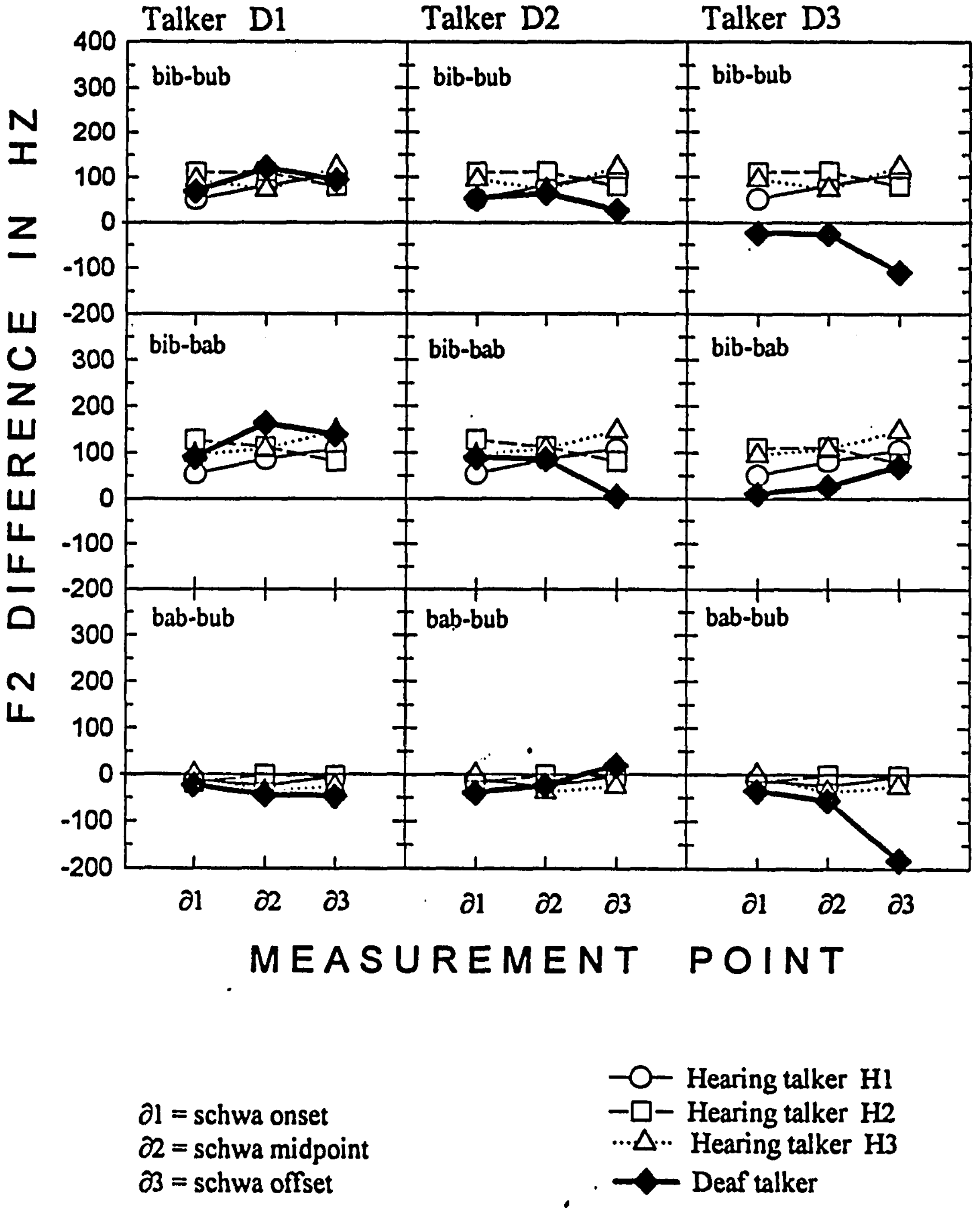


Figure 3.16: F2 differences of bilabial disyllables with contrasting vowel context at three measurement points, schwa onset, schwa midpoint and schwa offset. Each deaf talker is compared with the hearing talkers. The second member of the disyllable pair is subtracted from the first.

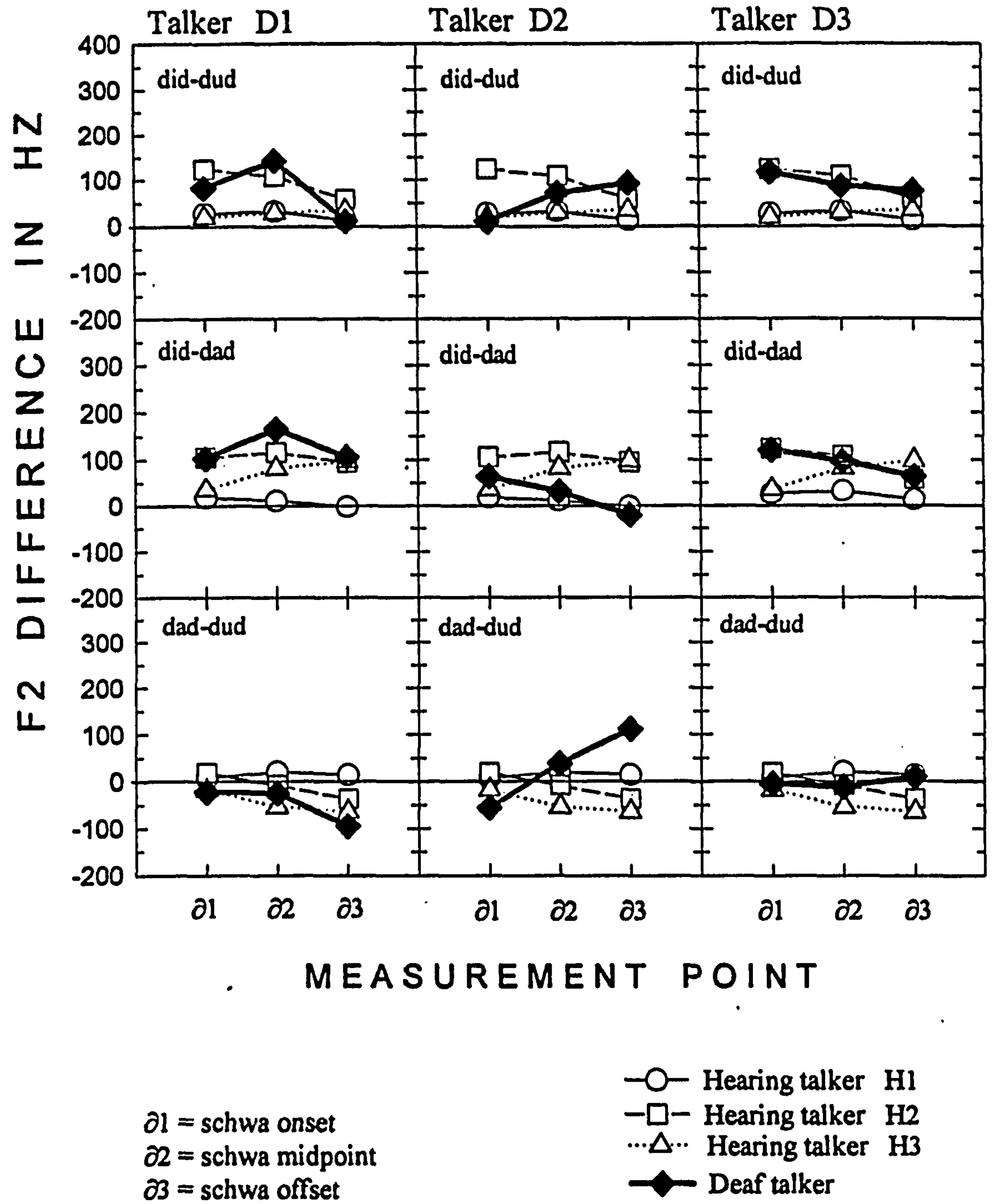


Figure 3.17: F2 differences of alveolar disyllables with contrasting vowel context at three measurement points, schwa onset, schwa midpoint and schwa offset. Each deaf talker is compared with the hearing talkers. The second member of the disyllable pair is subtracted from the first.

Table 3.22: Comparison of anticipatory coarticulation of the stressed vowel at comparable durations, across subjects. Planned comparisons of F2 means of contrastive disyllables are shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level.

Normal rate							Fast rate					
Disyllables	Hearing	∂1	∂2	∂3	Ton	Vm	Deaf	∂1	∂2	∂3	Ton	Vm
/bib/-/bab/	H1	*.0491	*	*	*	*	D1	*	*	*	*	*
/bib/-/bab/	H2	*	*	*	*	*	D2	*.009	*.019		*	*
/bib/-/bab/	H3	*	*	*	*	*	D3				*	*
/bib/-/bub/	H1	*.0097	*	*	*	*	D1	*	*	*.009		*
/bib/-/bub/	H2	*	*	*	*	*	D2				*	*
/bib/-/bub/	H3	*.0054	*.0114	*	*	*	D3			*.0069	*	*
/bab/-/bub/	H1				*	*	D1				*	*
/bab/-/bub/	H2				*.0194	*	D2				*.0053	*
/bab/-/bub/	H3					*	D3			*	*	*
/did/-/dad/	H1				*	*	D1	*	*	*	*	*
/did/-/dad/	H2	*	*	*	*	*	D2	*.059				*
/did/-/dad/	H3		*	*	*	*	D3	*	*		*	*
/did/-/dud/	H1				*	*	D1	*	*		*.0282	*
/did/-/dud/	H2	*	*	*.0248	*	*	D2		*.954	*.0297	*	*
/did/-/dud/	H3				*	*	D3	*	*.008	*.0584	*	*
/dad/-/dud/	H1				*	*	D1			*.0101	*	*
/dad/-/dud/	H2				*	*	D2			*.008	*	*
/dad/-/dud/	H3		*.0420	*.0160	*	*	D3					*

3.4.1.2 Coarticulation of vowels conditioned by consonant context, at comparable durations

Table 3.23 shows the significant patterns of F2 mean differences in disyllables of identical vowel environment and contrastive consonant contexts, at comparable rates across groups. Overall, at comparable durations, the hearing talkers showed greater temporal anticipation of consonant context than the deaf talkers. The anticipatory coarticulation conditioned by consonant context is always seen at schwa onset for the hearing talkers and as early as schwa midpoint for some the deaf talkers (an exception is noted for talker D3 who anticipated consonant context at schwa onset in disyllables containing vowel [i]).

3.4.1.3 Discussion and conclusions.

Intersubject differences in the anticipatory coarticulation vowel centers were observed among the deaf talkers. These relate to intelligibility differences among the deaf talkers. As indicated in the methods chapter, deaf talker D1 has considerably higher word recognition scores and intelligibility scores than the other two deaf talkers. D1's patterns on anticipatory coarticulation of vowel centers in bilabial contexts at comparable rates are very similar to the ones shown by the hearing talkers. It is concluded that deaf talker D1 somehow makes better use of his hearing capacity and that this is reflected on his intelligibility scores and his capacity for interarticulatory coordination (vowel-to-vowel coarticulation in bilabial contexts).

At comparable durations, the hearing and the deaf talkers did not exhibit similar coarticulatory patterns. In anticipation of consonant context, the hearing talkers showed uniformly greater temporal anticipation but anticipation of the vowel did not follow the same pattern. The anticipation of front vs. back vowel contexts is greater in hearing than the deaf talkers for disyllable productions involving intergestural coordination, i.e. labial and lingual movement. The pattern reverses for disyllables articulated with intragestural coordination, i.e. lingual movement only. Analysis of disyllable durations was made to examine whether unequal durations among disyllable types in within-talker productions of the deaf

Table 3.23: Comparison of anticipatory coarticulation of consonant context at comparable durations, across subjects. Planned comparisons of F2 means of contrastive disyllables are shown at five measurement points, i.e. schwa onset (∂1), schwa midpoint (∂2), schwa offset (∂3), transition onset (Ton) and vowel midpoint (Vm). The significant results are indicated with an asterisk, at .005 level of significance, according to the Bonferroni correction. Results significant at .05 level of significance are also noted with an asterisk and the actual p level.

Normal rate							Fast rate					
disyllables	hearing	∂1	∂2	∂3	Ton	Vm	deaf	∂1	∂2	∂3	Ton	Vm
/bib/-/did/	H1	*	*	*	*		D1			*		
/bib/-/did/	H2	*	*	*			D2		*.0281	*		
/bib/-/did/	H3	*	*	*			D3	*	*	*	*	
/bub/-/dud/		*	*	*	*	*				*		*
/bub/-/dud/		*	*	*	*	*			*.0431	*	*	*.018
/bub/-/dud/		*	*	*	*	*				*.0216	*	
/bab/-/dad/		*	*	*	*					*	*	
/bab/-/dad/		*	*	*	*	*.0219			*	*	*	
/bab/-/dad/		*	*	*	*				*	*	*	

group were responsible for the disparate anticipatory patterns observed in bilabial vs. alveolar context, i.e. greater anticipatory coarticulation in alveolar than bilabial disyllables. Table 3.24 lists the average durations (in msec) of each disyllable type at normal and fast rate for each talker. An inspection of Table 3.24 indicates that the durations of alveolar disyllables were not shorter than bilabial disyllables, at any rate and for any talker. Thus, the assumption of context-specific durational change in one group (hearing or deaf) is not supported.

A further examination of schwa durations was undertaken to find out whether the deaf talkers exhibit shorter schwa durations in alveolar than bilabial contexts. Table 3.25 lists the average durations (in msec) of schwa for each disyllable at normal and fast rate. An inspection of Table 3.25 indicates that the deaf talkers did not exhibit shorter schwa durations for alveolar than bilabial disyllables at either rate. Although within-talker differences across contexts were noted for durational shortening of schwa, no pattern was discerned. Thus, the different coarticulatory patterns observed for the hearing and the deaf talkers are a product of different articulatory organization.

Table 3.24: Average durations (in msec) of disyllables for each talker at normal and fast rates. Columns 8 and 16 show t
each consonant context pooled over vowel category. The ratio of durations at fast over normal rates indicates
change at fast rate.

	∂bib		∂bub		∂bab		∂bVb		∂did		∂dud	
	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast
H1	292.23	206.86	274.19	199.24	310.29	212.66	292.24	206.25	291.7	200.62	283.63	195.7
ratio	0.708		0.727		0.685		0.706		0.688		0.69	
H2	346.73	242.56	340.76	263.92	357.15	258.63	348.21	255.04	350.78	229.39	349.34	227.5
ratio	0.7		0.775		0.724		0.732		0.654		0.651	
H3	273.34	191.74	261.73	195.3	277.93	203.27	271.00	196.77	259.03	193.07	258.94	192.3
ratio	0.701		0.746		0.731		0.726		0.745		0.743	
D1	458.13	253.53	456.25	244.65	459.9	232.73	458.09	243.64	479.06	259.75	474.78	255.2
ratio	0.553		0.536		0.506		0.532		0.542		0.538	
D2	1036.5	568.76	1067.7	612.05	1010	550.44	1038.06	577.08	1104.6	625.62	1083	61
ratio	0.549		0.573		0.545		0.556		0.566		0.571	
D3	539.31	409.37	518.59	447.05	469.01	392.64	508.97	416.35	504	417.7	487.79	420.3
ratio	0.759		0.862		0.837		0.818		0.829		0.862	

and fast rates. Columns 8 and 16 show the durations for
ations at fast over normal rates indicates the durational

	ədid		ədud		ədad		ədVd	
t	**Normal**	**Fast**	**Normal**	**Fast**	**Normal**	**Fast**	**Normal**	**Fast**
6.25	291.7	200.62	283.63	195.73	321.62	214.19	298.98	203.51
	0.688		**0.69**		**0.666**		**0.681**	
5.04	350.78	229.39	349.34	227.54	390.53	267.49	363.55	241.47
	0.654		**0.651**		**0.685**		**0.664**	
6.77	259.03	193.07	258.94	192.36	290.59	221.21	269.52	202.21
	0.745		**0.743**		**0.761**		**0.75**	
3.64	479.06	259.75	474.78	255.22	481.08	264.01	478.31	259.66
	0.542		**0.538**		**0.549**		**0.543**	
7.08	1104.6	625.62	1083	618	1070.2	603.52	1085.96	637.64
	0.566		**0.571**		**0.564**		**0.587**	
16.35	504	417.7	487.79	420.37	478.32	382.63	490.04	406.90
	0.829		**0.862**		**0.8**		**0.83**	

Table 3.25: Average durations of schwa (in msec) for disyllables for each talker at normal and fast rates. Columns 8 and 16 sl the durations for each consonant context pooled over vowel category. The ratio of durations at fast over normal rat indicates the durational change at fast rate.

	S c h w a												
	∂bib		∂bub		∂bab		∂bVb		∂did		∂dud		∂da
	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast	Nor
H1	64.13	45.46	57.90	51.22	49.99	35.05	57.34	43.91	60.27	46.49	68.62	51.24	
ratio	0.71		0.88		0.70		0.77		0.77		0.75		
H2	55.33	37.63	55.94	38.68	48.61	29.43	53.29	35.25	46.06	21.55	55.55	29.48	
ratio	0.68		0.69		0.61		0.66		0.47		0.53		
H3	48.51	32.95	41.28	28.55	36.46	26.20	42.08	29.23	55.22	36.98	53.14	34.62	
ratio	0.68		0.69		0.72		0.69		0.67		0.65		
D1	138.30	72.04	117.58	70.15	121.65	60.36	125.84	67.52	147.67	77.09	136.65	79.06	1
ratio	0.52		0.60		0.50		0.54		0.52		0.58		
D2	260.41	97.78	256.08	95.04	247.68	100.81	254.72	97.88	333.89	223.93	280.42	109.14	2
ratio	0.38		0.37		0.41		0.38		0.67		0.39		
D3	137.12	89.16	129.32	102.78	134.48	118.36	133.64	103.43	136.16	94.07	135.89	104.76	1
ratio	0.65		0.79		0.88		0.77		0.69		0.77		

normal and fast rates. Columns 8 and 16 show
e ratio of durations at fast over normal rates

	∂did		∂dud		∂dad		∂dVd	
	Normal	Fast	Normal	Fast	Normal	Fast	Normal	Fast
1	60.27	46.49	68.62	51.24	57.02	39.17	61.97	45.63
	0.77		0.75		0.69		0.74	
5	46.06	21.55	55.55	29.48	52.86	30.90	51.49	27.31
	0.47		0.53		0.58		0.53	
3	55.22	36.98	53.14	34.62	48.59	34.12	52.32	35.24
	0.67		0.65		0.70		0.67	
2	147.67	77.09	136.65	79.06	128.77	71.25	137.70	75.80
	0.52		0.58		0.55		0.55	
8	333.89	223.93	280.42	109.14	288.41	116.31	300.91	149.80
	0.67		0.39		0.40		0.50	
3	136.16	94.07	135.89	104.76	125.90	99.24	132.65	99.36
	0.69		0.77		0.79		0.75	

3.4.3. Relations between separation of vowel centers and temporal and spatial aspects of anticipatory coarticulation in hearing vs. deaf talkers at comparable durations

The separation of vowel centers is defined as the F2 difference at vowel midpoint between disyllables contrasting in vowel context.

The research question of this section is: Is separation of vowel centers associated with the amount of anticipatory coarticulation of vowel context in hearing and the deaf talkers at comparable rates?

A between-group analysis was made to examine whether the F2 differences, averaged across talkers within a group, are significantly different across groups at each measurement point. The F2 differences, each representing the mean of F2 differences across 10 tokens of the same utterance were analyzed as a function of "subject type", "consonant type" and "vowel type". Table 3.26 below presents the planned comparisons of a 6x2x3 multivariate analysis of variance (Appendix E).

Table 3.26: Planned comparisons of F2 differences across groups

	F2 DIFFERENCE IN HZ					
Measurement Point	bib/bub	bib/bab	bab/bub	did/dud	did/dad	dad/dud
Vowel Midpoint	H>D p<.005	H>D p<.005	H<D p<.005	H>D p<.005	H>D p<.005	H<D p<.04
Transition Onset	H>D p<.005	H>D p<.005	H<D p<.005	H>D p<.005	H>D p<.005	H<D p<.94
Schwa Offset	H>D p<.005	H=D p<.12	H<D p<.01	H=D p<.44	H<D p<.01	H=D p<.12
Schwa Midpoint	H>D p<.10	H=D p<.77	H=D p<.28	H=D p<.44	H=D p<.95	H=D p<.32
Schwa Onset	H>D p<.030	H=D p<.22	H=D p<.17	H=D p<.25	H=D p<.73	H>D p<.26

When comparing group average F2 differences, one notes: a) significant differences between groups at vowel midpoint and b) nonsignificant differences between groups during schwa. If one inspects the p level values, the pattern during schwa is stronger for alveolar disyllables. In one comparison, /bib/-/bub/, the difference in F2 separation at vowel midpoint is correlated with the differences in F2 separation during schwa across groups.

A within-group analysis was made to examine whether the amount of vowel separation is associated with the extent of anticipatory coarticulation in one group but not another. Table 3.27 presents the raw F2 differences for each talker at vowel midpoint and schwa midpoint as well as the measurement point at which the F2 differences were first noted to be significant.

In Table 3.27, one notes the following:

1. In the hearing talkers, there is a relationship between context and vowel separation, i.e. the ranking of the magnitude of vowel separation with context follows a similar order. This relationship is not noted in the deaf talkers. For example, we see that for all the hearing talkers the F2 separation in /bib-bub/ is greater than in /bib-bab/, the F2 separation in /bib-bab/ is greater than in /did-dad/, etc.

2. In the hearing talkers, the magnitude of F2 separation at vowel midpoint can fairly well predict the magnitude of F2 separation at schwa midpoint. The

pattern is stronger for H1 and H2. The pattern is less consistent for the deaf talkers.

3. In the hearing talkers, the temporal onset of anticipatory coarticulation can be fairly well predicted by the F2 separation at vowel midpoint. The larger the F2 separation at vowel midpoint the earlier the onset of anticipatory coarticulation (although the pattern is not seen in one hearing talker, H3). The above relation is not observed in the deaf talkers.

Table 3.27: A comparison of F2 differences at vowel midpoint with F2 differences at schwa midpoint and onset of coarticulation across contexts.

Hearing talkers	F2 diff. at Vm	Disyllables	Onset of coartic.	F2 diff. at ∂2	Deaf talkers	F2 diff. at Vm	Disyllables	Onset of coartic.	F2 diff. at ∂2
H1	1273	bib-bub	1	82	**D1**	485	bib-bab	1	164
	1039	bib-bab	1	86		413	did-dad	1	166
	1037	did-dad	4	11		414	did-dud	1	142
	889	did-dud	4	32		-327	bab-bub	4	-42
	241	bab-bub	4	-24		158	bib-bub	1	122
	-174	dad-dud	4	21		1	dad-dud	3	-24
H2	1138	bib-bub	1	112	**D2**	543	did-dud	2	72
	1008	bib-bab	1	112		481	bib-bub	4	65
	977	did-dad	1	116		406	bib-bab	1	87
	757	did-dud	1	108		292	dad-dud	3	39
	-220	dad-dud	4	-8		252	did-dad	1	32
	129	bab-bub	4	0		75	bab-bub	4	-22
H3	1070	bib-bub	1	67	**D3**	853	did-dud	1	87
	890	bib-bab	1	95		811	bib-bub	3	-26
	846	did-dad	2	82		572	bab-bub	3	-54
	517	did-dud	4	29		566	dad-dud	5	-11
	-329	dad-dud	2	-53		286	did-dad	1	97
	180	bab-bub	5	-28		239	bib-bab	5	28

3.4.4 THE RELATION BETWEEN NUMBER AND DISTRIBUTION OF CONTRASTIVE VOWELS AND ANTICIPATORY COARTICULATION

The question addressed at this section is: Is anticipatory coarticulation in the deaf talkers related to the number and distribution of contrastive vowels in their vowel systems?[22]

The relation between number and distribution of contrastive vowels and anticipatory coarticulation was explored within the deaf talkers in order to test the prediction drawn from crosslinguistic studies that language systems with wider distributions of vowel categories, and therefore, a smaller number of vowels than English allow greater intervocalic influences regardless of transconsonantal characteristics (Manuel & Krakow, 1984). Manuel & Krakow assessed that the fewer the vowel categories in a system the greater the width of distribution in the F1/F2 space. Since vowel-to-vowel influences are constrained by the speaker's need to maintain vowel distinctiveness, it was reasoned that language systems with more broadly-distributed vowel categories than English (and therefore with

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[22] The data discussed above have indicated no relationship between number and distribution of contrastive vowels and anticipatory coarticulation across talkers that differ in hearing status. The hearing talkers have larger vowel spaces than the deaf talkers. Yet, they did not consistently show more anticipatory coarticulation of vowel centers across contexts than the deaf talkers.

fewer vowel categories) would permit for greater vowel-to-vowel coarticulation. By the same reasoning as Manuel & Krakow, the deaf talkers will differ from each other with respect to vowel-to-vowel influences because they have idiosyncratic vowel systems which vary in width of distribution in F1/F2 space and distinctiveness of vowels.

In Figures 3.18, 3.19, and 3.20, ten English vowel categories were produced by each deaf talker in a h_V context. Ten repetitions were produced for each vowel category. The average F1/F2 values and their standard deviations are plotted for each deaf talker in the acoustic space. In the above figures it can be readily seen that in contrast to the pattern of the hearing talkers with different language systems, the width of distribution of vowel categories in the vowel spaces of the deaf talkers is not inversely related to the number of distinct vowel categories in the F1/F2 plot. The main rationale, however, for the comparison of vowel system characteristics and coarticulation is based on the effects of the width of vowel distribution on coarticulation rather than on the effects of the number of vowels. Thus, the focus for this comparison will be the amount of compression of the vowel space. In the deaf talkers a compressed vowel space has fewer distinct vowel categories. Thus, the deaf talkers with a compressed vowel space and fewer number of differentiated vowel categories will show reduced vowel-to-vowel coarticulation. However, although the vowel space of each of the three the deaf talkers is collapsed, the formant dimension in which vowel compression is greater varies from talker to talker. Based on this observation, it was decided to determine the number of differentiated vowel categories for each deaf talker along each formant dimension (F1 and F2) by inspection of F1/F2 plots. A vowel category was considered distinct when its dispersion (measured in standard deviation units) was not overlapping with the dispersion of other vowel categories along the F1 or F2 dimension. Thus along F2, the deaf talkers D1 and D2 have fewer differentiated vowel categories (2), and deaf talker D3 has more number of differentiated categories (4).

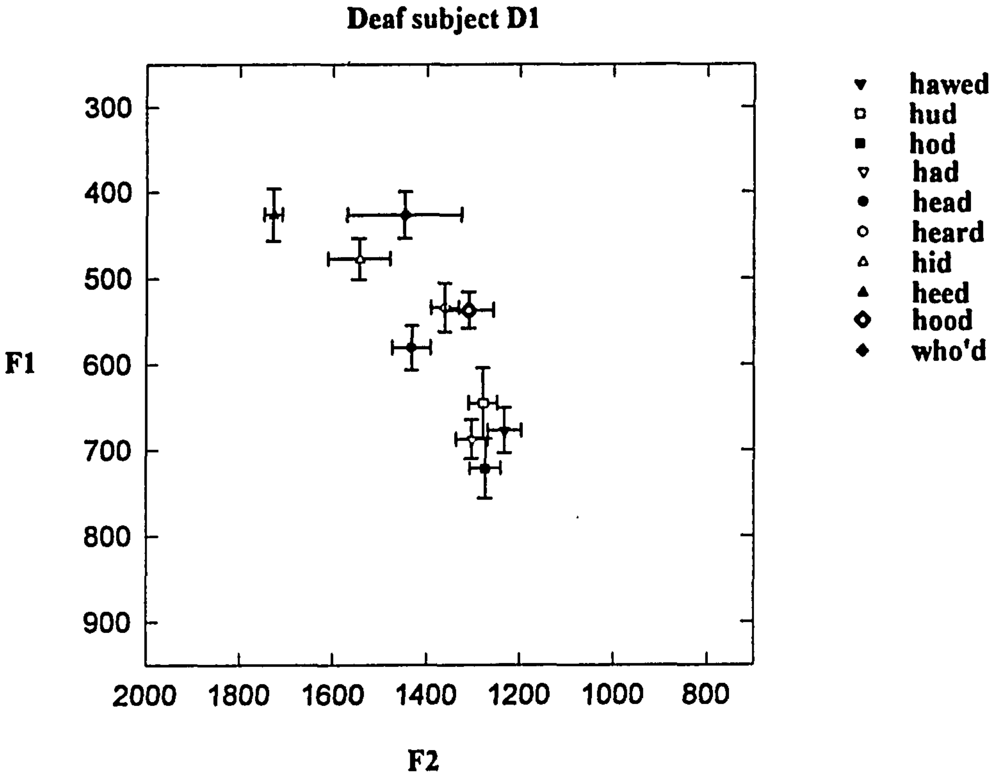

Fig. 3.18: Ten vowels embedded in an h-d context are plotted in a F1/F2 acoustic space for deaf talker D1. The symbols show the average value in Hz for different vowels and the bars show the standard deviation over ten tokens.

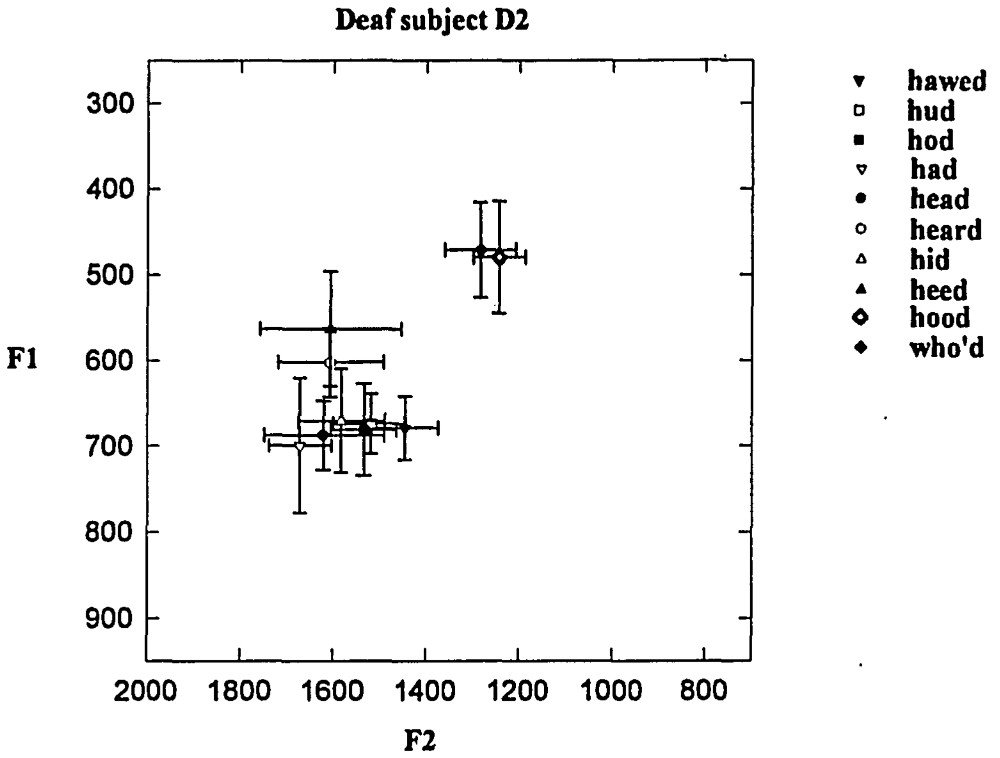

Fig. 3.19: Ten vowels embedded in an h-d context are plotted in a F1/F2 acoustic space for deaf talker D2. The symbols show the average value in Hz for different vowels and the bars show the standard deviation over ten tokens.

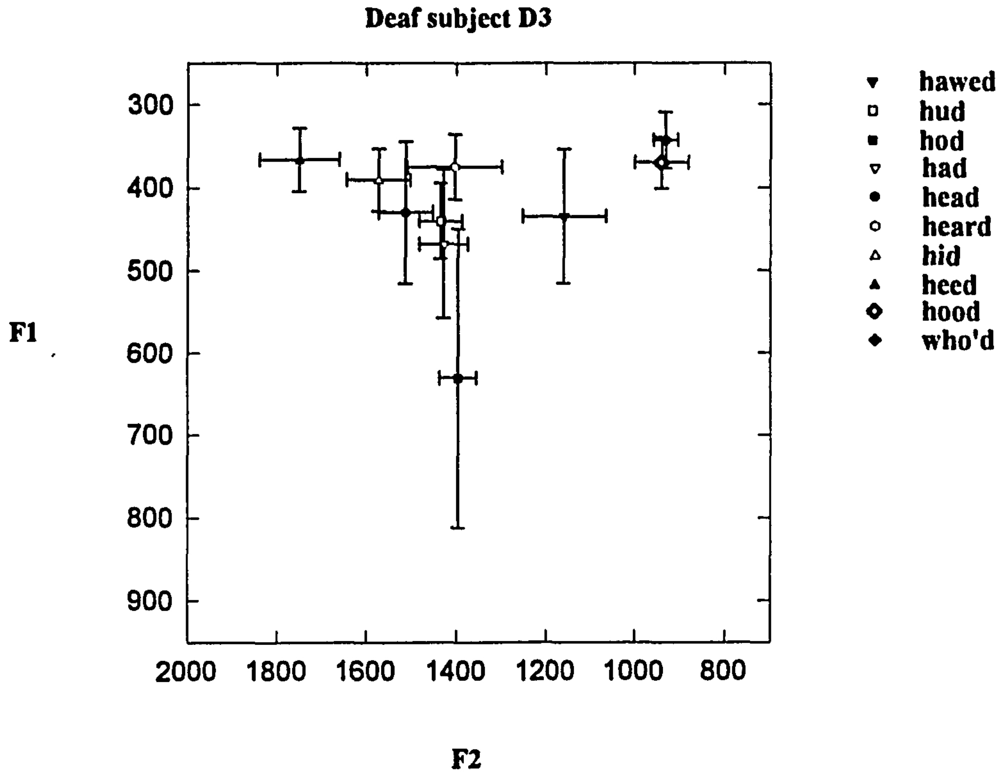

Fig. 3.20: Ten vowels embedded in an h-d context are plotted in a F1/F2 acoustic space for deaf talker D3. The symbols show the average value in Hz for different vowels and the bars show the standard deviation over ten tokens.

Along F1, D3 has the least number of differentiated vowel categories (0), D2 has two distinct categories and D1 has the greatest number of distinct vowel categories (3).

A relationship between number and distribution of contrastive vowel categories and extent of anticipatory coarticulation was not clearly observed in these data. Talkers D1 and D2 have a more compressed vowel space and a smaller number of distinct vowels (2) along the F2 dimension than talker D3. However, they do not consistently show less anticipatory coarticulation of vowel centers than D3. Talker D2 tends to show the least anticipatory coarticulation of vowel centers across contexts, a finding in the expected direction. However, talker D1 shows more anticipatory coarticulation of vowel centers than the other deaf talkers in some contexts (/∂bib/-/∂bab/, /∂bab/-/∂bub/ and /∂dad/-/∂dud/), a finding not in the expected direction. Talker D3 has the widest distribution of vowel categories along the F2 dimension, nevertheless, he does not exhibit the greatest coarticulation than the other two deaf talkers in all contexts.

Inconsistent trends are also noted in the relation between number and distribution of vowel categories along F1 and the anticipatory coarticulation of vowel centers. Talker D1 has the broadest distribution and the greatest number of distinct vowels along the F1 dimension. In disyllables contrasting in high/low back vowels he shows more anticipatory coarticulation than the other deaf talkers, across contexts. This trend is consistent with Manuel & Krakow prediction, however, it did not hold in comparisons among the other the deaf talkers. For example, talker D2 did not show greater anticipation of vowel centers than D3 in disyllables contrasting in high/low back vowel contrasts even though the latter talker has the most compressed vowel space along F1 and the least number of differentiated vowels.

DISCUSSION

The purpose of this study was to compare the role of context as it appears in the intra- and intersyllabic patterning of speech produced by deaf and hearing adults. Systematic observation of spectral and durational parameters in disyllable productions (ə#CVC) at normal and fast speaking rates was employed in order to relate inferences about articulatory adjustments with their temporal coordinates, an approach consistent with the coproduction model of speech production (Fowler, 1980; Bell-Berti & Harris, 1981; Browman & Goldstein, 1986). Vowel system differences among deaf and hearing individuals will be taken into account in interpretation of data (Manuel and Krakow, 1984).

4.1 THE ROLE OF CONTEXT IN THE SPEECH OF HEARING AND DEAF TALKERS

The research questions addressed in section 3.1.1 were:

1) What is the distribution in F1/F2 space of point vowels in the hearing and the deaf talkers of this sample?

2) What is the effect of context on each talker's distribution of point vowels [i], [u] and [a]?

3) What patterns are discerned if one examines the effects of context on the distribution of point vowels in relation to hearing status?

The findings in section 3.1.1 of this study contradict preexisting notions of the role of context in speech of the deaf. It has been proposed that the integration of contextual variation into productions by deaf speakers is a laborious process, that often leads to their distortion of vowel targets that they can successfully produce in stationary or isolated fashion (Rothman 1976). Alternatively, more contemporary accounts offer milder versions of context "intrusiveness" by suggesting that deaf talkers show reduced overall contextual sensitivity to upcoming segments (Waldstein & Baum, 1991).

In this study, a comparison of the F1 and F2 vowel positions for isolated vs. embedded productions [i], [u], [a] in the acoustic space indicated greater F2 differences among vowels in the embedded than isolated condition for the deaf but not the hearing talkers. Such increases in F2 difference in front vs. back vowels were induced either by coarticulatory effects, i.e. influences of the surrounding context on vowel centers or by "calibration" effects, i.e. F2 differences not related to coproduction principles of phonetic segments (see below).

Hence, the higher F2s seen in D2 for high vowel centers, [i] and [u], in alveolar as compared to isolated conditions, are a result of coarticulatory influences. They lead to an expansion of the front-back vowel dimension. In contrast, D3 shows lower F2 frequency for the [u] center in alveolar and bilabial contexts as compared to the isolated condition. D2 shows the same effect for the

[u] center in alveolar compared to the isolated condition. By inference, it is more likely that the F2 effect in embedded conditions reflects more posterior lingual constrictions rather than lip rounding of the surrounding consonant targets because F1 is higher in the embedded conditions compared to the isolated ones (the possibility that greater lip rounding is accompanied by greater lip opening can not be entirely ruled out because oftentimes the deaf talkers show aberrant speech patterns).

The lower F2s in [u] result in greater F2 differentiation of high front/back vowel centers, but this differentiation is probably not caused by coarticulatory effects (such as lip rounding). Note that for D1 and D3, the [u] center values in the alveolar condition more closely resemble the Peterson and Barney (1952) values than their [u] in isolation. Given that vowel production requires more precise speech motor control (Perkell & Nelson, 1981) than consonant production and more fine-tuning via auditory input, it seems that these two deaf talkers are aided in achieving more "accurate" [u] productions by anchoring the tongue at points of articulatory contact between vowel productions. This is consistent with the account that deaf speakers rely on tactile feedback in the oral cavity in their speech and often tend to maximize it by enforcing hard articulatory contacts (Boothroyd, 1982). Also, a Consonant-Vowel (CV) production pattern is a fundamental organization in early developing speech, observed in infants' early babbling regardless of hearing status. Hence, the CV production is an inherently more “natural” way of producing sounds. It is concluded that gross patterns of CV sequencing (alternating stages of closed vs. open vocal tract) play a “calibrating” role for the deaf talkers by inducing vocal tract adjustments that differ from the isolated vowel productions in idiosyncratic ways. Respectively, in this case, the F2 lowering in /dud/ compared to /u/ may be attributed either to unorthodox lip rounding (greater lip rounding + greater lip opening in /dud/ than /u/) or to aberrant lingual movement to and from consonantal contacts.

The hearing talkers did not show such an effect. In contrast, the acoustic F1 or F2 differences in isolated vs. bilabial vs. alveolar conditions suggest that they assumed more extreme positions in the isolated and bilabial than alveolar conditions. Thus, in the hearing talkers, vowel productions reach more extreme positions in the vocal tract when constraints of consonant context are minimized. A characteristic example can be found in the smaller F2 differences between /i/ and /u/ centers in the alveolar compared with the isolated conditions. The F1/F2 values of vowels in the isolated condition conform to Peterson and Barney (1952) values for the same vowels. Thus, the hearing talkers have achieved better speech motor control of isolated vowel targets.

The hearing talkers also exhibited some "calibration" effects with respect to isolated vs. embedded vowel productions. For two talkers F1 was higher for isolated /a/ than it was in /bab/ and /dad/. One infers higher jaw positions (and higher tongue height) for embedded than isolated [a]. A safe conclusion about the productions of the hearing talkers in context-free vs. context-embedded conditions is that context does not induce greater differentiation between vowel categories.

Moreover, the hearing talkers showed consistency in the size and shape of vowel distributions within and across conditions. The vowel space was most collapsed in the alveolar condition for all the hearing talkers. In contrast, the deaf talkers differed from each other in the size and shape of vowel distributions, both within- and across- conditions.

4.2. INTRASYLLABIC PATTERNING AT THE MIDPOINT OF THE STRESSED VOWEL IN /əCVC/ PRODUCTIONS -- F2 COARTICULATORY EFFECTS.

In section 3.1.2, the F2 effects of isolated vs. bilabial vs. alveolar context were assessed at vowel midpoint. The research questions addressed were:

1) Are the hearing talkers more likely than the deaf talkers to show significant context-conditioned F2 differences at vowel midpoint?

2) Are context effects in the expected direction in both groups, i.e. a lower midvowel F2 as a result of lip rounding in bilabial context and a higher midvowel F2 as a result of tongue fronting in alveolar context?

The deaf talkers showed as many instances of significant F2 shifts with context as the hearing talkers. However, in the hearing group, the F2 shifts tended to occur in expected directions, i.e. a lower F2 in bilabial as compared with isolated conditions and, for back vowel centers, a higher F2, in alveolar as compared with bilabial conditions. The deaf talkers tended to show idiosyncratic, aberrant patterns in their F2 shifts with context, such as a higher F2 for high vowel centers in bilabial than isolated conditions (D1 and D2), lower F2 for [u] in alveolar as compared with bilabial conditions (D1 and D2), higher F2 for [i] in alveolar than isolated conditions and a lower F2 for [u] in alveolar than isolated conditions (D1 and D3).

With respect to contextual influences, the F2 of the hearing talkers for [u] was significantly higher in alveolar than in bilabial productions suggesting effects of coarticulation within the stressed syllable as a result of alveolar context. The F2 of the deaf talkers was either similar across the two context types (nonsignificant differences for talker D3) or higher in bilabial than alveolar productions (talkers D2 and D1). The latter finding is puzzling because the intersegmental coordination in bilabial CVC syllables is carried by two separate articulators, the lips for the bilabial gesture and the tongue for the vowel gesture. It is, thus, unlikely that coarticulatory effects between back vowel constrictions and anterior consonant context b_b are in operation. Alternatively, one may ascribe the event to extraneous peculiarities that often accompany the speech production of the deaf talkers. An examination of the acoustic records of bilabial and alveolar syllables with [u] centers revealed a higher F0 for the bilabial condition in both D1 and D2. It is possible, then, that in bilabial productions a) the tongue moves forward because it is not constrained by a consonantal contact and b) greater tension occurs in the upper articulators and the larynx when intersegmental production demands entail the coordination of two independent articulatory subsystems rather than one (the tongue). The tension causes F0 increase which in turn might cause genioglossus activity due to the physiological linkage of posterior fibers of the genioglossus muscle with the hyoid bone. Honda (1981) and Bush (1981) have demonstrated that upward F0 shifts may be caused by a forward and upward bunching of the genioglossus muscle because its posterior fibers are linked to the hyoid bone. In Bush's study, deaf speakers showed a positive correlation between F0 and tongue height. According to her account, the observed physiological linkage between F0 effects and tongue movement "fades away" in developed speech via compensatory physiological adjustments of pitch control.

The above explanations seem more plausible than a coarticulatory account because the latter does not predict more coarticulation for bilabial than alveolar context. It is concluded that the deaf talkers do not exhibit the intrasyllabic coarticulatory influences seen in the speech of the hearing talkers. Thus, they show reduced contextual sensitivity at [u] midpoint with respect to alveolar context. This finding conforms with previous accounts of coarticulation in deaf talkers posited in acoustic studies which also state that deaf talkers exhibit reduced contextual sensitivity compared to hearing talkers (Monsen, 1976; Rothman, 1976; Waldstein & Baum, 1991).

Further study of intrasyllabic coarticulation was made in section 3.2.1 where the effect of bilabial vs. alveolar context on F2 within the stressed syllable was examined in vowel-contrasting disyllables. The research question was: Do hearing and deaf talkers show similar patterns of coarticulatory influence of a given consonant environment on vowel center separation?

The order of F2 positions of vowel contrasts at vowel midpoint varied consistently with consonant context in the hearing talkers. The hearing talkers were systematic in their lower F2 in /əbub/ compared to /bib/ and /əbab/, in their higher F2 in /did/ compared to /dud/ and in their higher F2 in /ədud/ compared to /ədad/ (see Table 3.9).

The order of F2 positions of vowel contrasts at vowel midpoint did not vary consistently with consonant context in the deaf talkers. Contextual influences were either absent (e.g. D1 showed the same spectral order regardless of context: a higher F2 in /bub/ than /bab/ and in /dud/ than /dad/) or idiosyncratic (e.g. D2 showed a higher F2 in /bub/ than in /bab/ and a lower F2 in /dud/ than in /dad/). Moreover, in the deaf talkers, the vowel separation in front/back vowel contrasts was not greater in bilabial than alveolar contexts (see Table 3.9).

4.3. INTERSYLLABIC PATTERNING AT NORMAL RATE -- F2 COARTICULATORY EFFECTS ON THE SCHWA OF /əCVC/ UTTERANCES.

Section 3.2 examined the temporal extent of anticipatory coarticulation of upcoming vowel or consonant segments. The effects of the following consonant on the preceding schwa (in section 3.2.2) were studied in disyllables with contrasting consonant context and identical vowel environments. The research question was: What is the temporal extent of anticipatory coarticulation of the schwa /ə/ conditioned by consonant context in deaf and hearing talkers? The hearing talkers uniformly showed earlier anticipation of consonant context than the deaf talkers.

The effects of the stressed vowel on the preceding schwa (in section 3.2.1) were studied in disyllables with contrasting vowel context and identical consonant environments in order to draw conclusions about vowel-to-vowel influences in relation to hearing status. Schwa was chosen as the unstressed vowel which according to studies in normal production (Recasens 1985) provides the most sensitive context for examining anticipatory coarticulation.

The research question addressed to examine intersyllabic patterning at normal rate was: What is the temporal extent of anticipatory coarticulation of vowel constrictions in deaf and hearing talkers?

Both groups of subjects showed significant effects during some or all measurement locations in the schwa, even though the schwa and stressed syllable durations were greater for the deaf than for the hearing talkers. The comparison across groups, though, revealed a different trend by group across contexts. In bilabial disyllables contrasting in front vs. back vowels (/bib/ vs. /bab/ or /bub/), the temporal extent of vowel anticipation was greater in the hearing than the deaf talkers. In contrast, in alveolar disyllables contrasting in front vs. back vowels, the deaf talkers showed more instances of early anticipatory vowel coarticulation than the hearing talkers. Also, earlier anticipation was seen in bilabial disyllables with high/low back vowel contexts for the deaf than the hearing talkers. The above findings indicate that anticipation of vowel contexts was not greater in the hearing than the deaf talkers overall, but depended on the particular consonant-vowel combinations studied.

The finding on anticipation of vowel context runs counter to previous findings (Waldstein & Baum, 1991, Monsen, 1976b, Rothman 1976) and conclusions that deaf speakers' speech is less coarticulated than that of normals. According to the Monsen and Rothman accounts, the acoustic records of deaf speakers (adolescents and adults respectively) had flatter F2 transitions between vowel onset and vowel midpoint or "steady-state". Based on this finding they suggested that deaf speakers coarticulate less than hearing speakers. In the Waldstein and Baum study, deaf children aged 7 and 10 years were compared with their hearing counterparts. A comparison of F2 ratios of CV contrasts (ki/ku, ti/tu, si/su) taken 20 msec prior to vowel onset indicated larger ratios for hearing than the deaf talkers in the velar and palatal contexts. (Waldstein and Baum failed to account for the difference noted in the alveolar context where ratios of ti/tu were larger or equal in deaf as compared with hearing children, in the 7- and 10-year old group respectively).

Apart from the methodological problems with some of these studies (Monsen, 1976b; Rothman, 1976; see chapter 1), all studies above examined a small portion of the acoustic signal that corresponded to a short time window. The "flatter" transitions of the acoustic signal in such a small time window may lead to erroneous interpretation. Flatter transitions in the acoustic signal may also occur in cases of increased intergestural overlap of the same consonant vowel sequences provided that there is no articulatory conflict. In these cases, the tongue assumes its position for the upcoming vowel prior to consonant release.

Another problem of previous studies is the fact that coarticulatory patterns were directly compared in deaf vs. hearing speakers without a systematic account of vowel system differences. The F1/F2 vowel space of deaf speakers is smaller than normals' (see section 3.1 in this study; Rubin 1984; Subtelny, Whitehead & Samar, 1992) and, therefore, separation between contrastive utterances is less in deaf as compared to hearing speakers. When coarticulatory patterns are examined via cross group comparisons only, results are confounded by a failure to address vowel system differences. In the Waldstein and Baum study, the greater F2 ratios of /ki/:/ku/ and /si/:/su/ for hearing than deaf children at a prevocalic position of the acoustic signal are at least partly attributable to their greater /i/:/u/ ratios at vowel midpoint.

Finally, another methodological problem of the previous studies has been the lack of systematic comparison between spectral and temporal parameters. Since the speech of deaf speakers is slower than that of hearing speakers (Osberger and McGarr, 1982) one would expect less intersegmental overlap, and hence, less coarticulation. It is already apparent that findings in this study do not conform with the general prediction that the longer durations in speech of the deaf would yield reduced anticipatory coarticulation of schwa. The durations of both bilabial and alveolar disyllables were longer in the deaf than in the hearing talkers because the schwa durations of the deaf talkers were two or three times greater. Yet, in alveolar disyllables, early anticipation of front/back vowel center differences occurred more often in deaf than the hearing talkers. However, it may still be the case that the anticipatory coarticulation in bilabial disyllables becomes more comparable across groups at comparable rates.

An attempt was made to address these issues systematically. The effects of durational shortening, of vowel separation and of vowel system on coarticulation were examined in relation to hearing status. These findings are summarized below.

4.4. THE EFFECT OF RATE ON INTERSEGMENTAL PATTERNING -- TEMPORAL EXTENT OF ANTICIPATORY COARTICULATION IN DISYLLABLES AT COMPARABLE DURATIONS

The research questions addressed in sections 3.3 and 3.4 were:

1) Do all talkers, hearing and deaf, show significantly smaller phrase and segment durations when paced to speak faster?

2) Is the amount of durational shortening at fast rate on a par with previous studies of hearing talkers at self-selected rates?

3) Does coarticulation of vowel context by hearing and deaf speakers increase with increases in speaking rate?

4) Do increases in the temporal onset of anticipatory coarticulation of vowel context occur as a function of increased rate in the speech of hearing and deaf talkers?

5) Does coarticulation of vowels conditioned by consonant context increases with increases in speaking rate for hearing and deaf speakers?

6) Do increases in the temporal onset of anticipatory coarticulation of consonant context occur as a function of rate in the speech of hearing and deaf talkers?

7) Do the coarticulatory patterns of deaf talkers resemble those of hearing talkers at comparable durations?

Both hearing and deaf talkers showed significant durational shortening in the schwa and stressed syllable portions of disyllables at faster rates. The durational shortening for both hearing and deaf talkers at fast rate was on a par with previous studies of hearing talkers at self-selected rates.

In bilabial disyllables contrasting in front/back vowel centers, both hearing and deaf talkers' F2 differences revealed instances of greater anticipatory coarticulation of vowel context during schwa as a function of rate. These coarticulatory increases were not systematic for the deaf nor the hearing talkers but occurred more frequently for the hearing talkers. Coarticulatory changes in anticipation for disyllables contrasting in back, high/low vowels were not observed in the hearing or the deaf talkers, presumably because such contrasts do not differ much along F2. Overall, in alveolar disyllables, there were no spectral increases in anticipatory coarticulation of vowel context during schwa with rate.

Inspection of earlier onset of anticipatory coarticulation of vowel context during schwa indicated that the deaf talkers did not show systematic increases in bilabial context[23]. The lack of significantly earlier onsets by the deaf talkers may be related to their longer schwa or to poor interarticulatory coordination (see below). In alveolar disyllables, both hearing and deaf talkers exhibited few instances of earlier anticipation of vowel context at increased rate.

[23] note that temporal increases in the bilabial productions of the hearing talkers could not be assessed because their temporal onset occurred at the schwa onset in bilabial disyllables at normal rate.

With respect to the anticipatory coarticulation of consonant context as a function of rate, the hearing and the deaf talkers showed no spectral increases (increases in F2 difference) during schwa at fast rate. Furthermore, temporal changes were not systematic in direction for the deaf talkers [24].

A comparison of the fast-rate productions of the deaf talkers with the normal-rate productions of the hearing talkers revealed that the mean durations of disyllables were only roughly comparable across the two groups: at fast rate, the durations of the stressed syllable of D1 and D3 were similar to those of the the hearing talkers at normal rate, whereas the durations of the stressed syllable of D2 were longer those of the hearing talkers at normal rate. The schwa durations were uniformly longer in the fast-rate speech of the deaf talkers compared to the normal-rate speech of the hearing talkers.

At comparable durations, results remain, more or less, similar to the ones noted at normal rates. In bilabial disyllables contrasting in front vs. back vowel contexts, the hearing talkers showed greater temporal anticipation of the stressed vowel than did the deaf talkers. In alveolar disyllables contrasting in front vs. back vowel contexts, the deaf talkers showed greater temporal anticipation of the stressed vowel than the hearing talkers. In bilabial disyllables contrasting in back

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[24] note that the hearing talkers exhibited early anticipation of consonant context at normal rate, as early as schwa onset, thus, temporal increases with rate could not be assessed.

vowel contexts (/a-u/), the deaf talkers exhibited greater temporal extent of anticipation than the hearing talkers. Note, however, that a clear pattern did not emerge at comparable durations for alveolar disyllables contrasting in back vowel contexts. In disyllables contrasting in consonant context, the hearing talkers show earlier anticipation than the deaf talkers.

Overall, two predictions can be made from the literature. Prediction A holds that increases in speaking rate will result in greater anticipatory intervocalic coarticulation and prediction B holds the differences in anticipatory coarticulation across the two groups of talkers are solely related to their differences in duration. These predictions are only partly supported. Prediction A is supported for bilabial disyllables for the hearing, and to a smaller extent, for the deaf talkers. Prediction A is not supported for alveolar disyllables, contrasting in front/back vowels. One may attribute the reduced anticipation of front/back vowel centers in alveolar disyllables to gestural antagonism between consonant and vowel segments in the alveolar disyllable. The tongue dorsum activity for intervocalic influences is partly constrained during /d/ production (Recasens, 1989), thus, it does not allow greater intervocalic influences. Alternatively, this may just be a case in which intergestural overlap does not increase with rate as much when both consonant and vowel gestures are executed by a single articulator. Prediction B is also at least somewhat supported. Comparing vowel anticipation in bilabial disyllables at comparable rates across the hearing and the deaf talkers, one notes that deaf talker D1 exhibits a degree of vowel anticipation comparable to that of the hearing talkers. In D1's case a durational change (shortening) is solely responsible for the observed effect. Talker D2 has longer syllable durations at fast rate than do the hearing talkers' at normal rate. She exhibits temporal increases in vowel anticipation with increased rate in one context only. Bilabial disyllables contrasted in high front/low back vowel contrasts. Overall, her vowel anticipation is not comparable to the hearing talkers'. Talker D3 shows comparable syllable durations to the hearing talkers at his fast rate (D3's syllable duration at fast rate matches H2's syllable duration at normal rate), but his anticipatory coarticulation of vowel contexts is reduced in bilabial environments. D3's schwa duration continues to be at least twice as long the hearing talkers' durations. The absence of consistent increase in temporal vowel anticipation in D3's bilabial disyllables contrasting in front/back vowels may be related to the long duration of his schwa.

In sum, the relation between durational shortening and increased temporal anticipation was shown, more or less, for the bilabial but not alveolar context. In bilabial productions, the lack of similar anticipatory coarticulation of vowel context at comparable durations across the two groups of talkers may be related to the fact that, at fast rate, the schwa durations of the deaf talkers continued to be much longer than that of their hearing counterparts (sometimes twice as long). Thus, although the articulatory period for stressed vowel production overlaps more with schwa production at fast rates, the absolute time needed for appropriate execution of the stressed vowel, as suggested by frame theory (Bell-Berti & Harris 1981), could still be contained within the last part of schwa. In other words, at comparable rates, differences in stressed/unstressed syllable ratio persist and may therefore be responsible for the greater vowel anticipation of front/back vowel contexts by the hearing than by the deaf talkers. Recall, however, that in alveolar disyllables, anticipatory coarticulation of vowel context tends to be greater in the deaf than in the hearing group despite the longer schwa durations of the former group.

In addition, certain phenomena, which tended to minimize the rate effects, sometimes accompanied increases in rate. For the hearing and the deaf talkers, the effects of increased rate sometimes led to neutralization of some vowel centers, a possibility already documented in the literature (e.g. Tuller, Harris & Kelso, 1982). This neutralization resulted in smaller separation of vowel centers (as measured by the F2 difference between disyllable pairs at vowel midpoint), and, therefore, in reduced anticipatory coarticulation. In addition, there were consonant-vowel interactions such that the effects of consonant context affected the intervocalic coarticulation disproportionately for different vowels, leading to decreased F2 differences at fast rate. For example, the alveolar context induced F2 increases in the [u] center of /ədud/ compared to /əbub/. F2 increases of similar magnitude were not noted for /əbad/ compared to /əbab/. Hence, the absolute F2 difference between /ədud/ and /ədad/ is smaller than the one noted between /əbub/ and /əbab/.

4.5 VOWEL SEPARATION AT VOWEL MIDPOINT AND ITS RELATION TO ANTICIPATORY COARTICULATION -- COMPARISON ACROSS HEARING AND DEAF TALKERS AT COMPARABLE DURATIONS

The research question of section 3.4.3. was: Is separation of vowel centers associated with the amount of anticipatory coarticulation of vowel context in hearing and deaf talkers at comparable rates?

In section 3.4.3, it was shown that vowel differentiation, i.e. F2 differences at vowel midpoint, may be associated with, to a certain degree, the extent of anticipatory coarticulation. Comparisons between these two variables were made across hearing status at comparable durations, to avoid the confounding effects of durational differences. In certain cases, the magnitude of F2 differences at vowel midpoint (i.e. the F2 differences at normal rate in the hearing talkers -- see Table 3.16 -- and the F2 differences at fast rate in the deaf talkers --- see Table 3.17) in the hearing vs. the deaf talkers could account for the differences in anticipatory coarticulation (Table 3.22) across hearing status. This was observed for the bilabial but not for the alveolar context. Thus, in bilabial disyllables contrasting in front vs. back vowels, the hearing talkers showed greater F2 separation at vowel midpoint and greater anticipatory coarticulation at schwa than the deaf talkers. In bilabial disyllables contrasting in back vowels (a-u) the deaf talkers showed greater F2 separation at vowel midpoint and greater anticipatory coarticulation at schwa than the hearing talkers. Thus, we conclude that vowel separation at vowel midpoint can at least partly account for the reduced anticipatory coarticulation of vowel context observed in the deaf as compared to the hearing speakers in bilabial environments. However, the same trend was not found in alveolar environments.

Furthermore, data analysis within groups (Table 3.28) indicated that the relationship between vowel separation and anticipatory coarticulation held across contexts (bilabial/alveolar) for the hearing but not for the deaf talkers. A characteristic of the hearing speakers' productions was that the ranking of magnitude of vowel separation with context was robust for front/back vowel contrasts and followed the same order across talkers.

Selective inspection of tables 3.16 and 3.17 at comparable rates for the deaf and the hearing talkers provides some pair-matching examples across the two groups. It shows instances where the deaf talkers coarticulate more than, or similarly to, the hearing talkers even though they have reduced separation between contrastive vowel centers, and thus, flatter transitions. Some examples are :

a) talkers H1 and D3 in the /*ə*did/-/*ə*dad/ comparison: the F2 separation at vowel midpoint is much greater for hearing talker H1 than deaf talker D3 (1037 Hz and 226 Hz respectively). At schwa, however, D3 has a greater F2 difference than

H1 (i.e. at schwa onset: 121.2 Hz and 19 Hz, respectively). The latter differences show that intervocalic influences are greater in D3 than H1.

b) The same talkers (H3 and D1) in the /əbib/-/əbab/ comparison: the F2 separation at vowel midpoint is greater for hearing talker H3 than deaf talker D1 (890 Hz and 485 Hz respectively). At schwa midpoint and schwa offset, however, the F2 differences between contrastive syllables are roughly equal for the deaf and hearing talker, or slightly greater for D1 (i.e. at schwa midpoint: D1: 164 Hz, H3: 95 Hz; at schwa offset: D1: 139 Hz and H3: 139 Hz).

4.6. THE RELATION BETWEEN NUMBER AND DISTRIBUTION OF CONTRASTIVE VOWELS AND ANTICIPATORY COARTICULATION

The question addressed at 3.4.4 was: In deaf speakers, is there a relation between number and distribution of contrastive vowels and anticipatory coarticulation of vowel centers?

The relation between number and distribution of contrastive vowels and anticipatory coarticulation of vowel centers was explored within the deaf talkers in order to test the prediction drawn from crosslinguistic studies that systems with a broadly-distributed vowel categories allow greater vowel-to-vowel influences regardless of transconsonantal characteristics (Manuel & Krakow, 1984). In these data, the greater the compression of vowel space the less the number of differentiated vowels. Hence, it was expected that vowel systems with fewer differentiated vowels would exhibit reduced vowel-to-vowel influence. Data analysis was conducted for each acoustic dimension separately (F1 and F2 respectively) because all the deaf talkers have shown compressed vowel spaces in the F1 or the F2 dimension.

A relationship between the number of distinct vowel categories (and therefore, the width of distribution) along a single acoustic dimension, and extent of anticipatory coarticulation (F2 patterns) was not clearly observed in these data.

Possible explanations for the lack of relationship between vowel system characteristics and anticipatory coarticulation of vowel centers are: a) In contrast with the Manuel & Krakow (1984) study, the vowel data in this study were analyzed along each acoustic dimension separately (F1 and F2 respectively). Thus, the method for estimating vowel distinctiveness in this study differed from the Manuel & Krakow study. They have plotted several token productions for different vowels in a F1/F2 plot and derived vowel distinctiveness by looking at the number of nonoverlapping circles (i.e. vowel categories). In this study, it was not possible to replicate the method used by Manuel and Krakow because a) the vowel spaces of all three deaf talkers were compressed in one or another acoustic dimension (F1 or F2), b) talker D2's productions are substantially longer in duration than those of the other two deaf speakers who have similar durations to each other, thus, D2's patterns are confounded by durational differences and c) in these data, the width of distribution and number of distinct vowel categories were not inversely related as seen in the Manuel & Krakow (1984) study.

4.7. IMPLICATIONS AND CONCLUSIONS BASED ON THE FINDINGS OF THIS STUDY

The findings in this study, with respect to both vowel and consonant anticipation during schwa, strongly suggest that the deaf talkers have a different articulatory organization from that of the hearing talkers. Each of the following results points towards the above conclusion:

a) None of the examined variables, i.e. durational differences among the deaf and the hearing talkers and differences in vowel separation and vowel system characteristics, could account fully for the coarticulation findings in this study.

If durational differences were responsible for the coarticulation differences between the hearing and the deaf talkers, one would observe less coarticulation in the speech of the deaf than the hearing talkers because the segment durations of the former are longer and overlap less in intersegmental coordination. However, despite their longer durations, the deaf talkers showed greater anticipatory coarticulation of upcoming vowels in disyllables /∂dVd/ than the hearing talkers. Moreover, at comparable durations, the anticipatory coarticulation of vowels in disyllables /∂bVb/ and the anticipatory coarticulation of consonant context were temporally equal in the two groups. In

/ðbVb/, the hearing talkers showed earlier anticipation of vowel centers during the schwa.

If vowel system differences were responsible for the coarticulation differences across the two groups one would expect that the hearing talkers, who consistently show greater separation between vowel categories, would show more anticipatory coarticulation of upcoming vowels across consonant contexts. The data, though, indicated that for alveolar consonant contexts anticipatory coarticulation of vowels was greater in the deaf talkers than the hearing talkers.

b) At comparable rates, the anticipatory coarticulation of consonant context was reduced in the deaf compared to the hearing talkers. This finding occurred even though the anticipation of the vowel following the consonant was sometimes greater in the deaf than the hearing talkers (as discussed above). The above pattern of findings does not conform with the expectation of coarticulation models in normal production, that anticipatory effects are greater for immediately upcoming segments (the consonant) than following ones (the vowel). The hearing talkers, in agreement with the coarticulation models, consistently showed anticipatory coarticulation of consonant context, as early as schwa onset in all disyllable comparisons.

c) The results on coarticulation of consonant context have further indicated that the spectral effects of consonant formation differ in the deaf and the hearing talkers. In the hearing talkers, the transition onset showed greater F2 differences between /∂bub/-/∂dud/ and /∂bab/-/∂dad/ pairs than the schwa offset. In the deaf talkers, the transition onset did not show showed greater F2 differences than the schwa offset.

One example of differences in consonant formation between the hearing and the deaf talkers is provided below. Figures 4.1-4.3 below, indicate that the deaf talkers D2 and D3 show a different F2 slope from the hearing talkers between schwa offset and transition onset in /∂dud/. These deaf talkers (Fig.4.2-4.3) tend to have a flat F2 slope between schwa offset and transition onset in /∂dud/. In contrast, all the hearing talkers showed a positive F2 slope between schwa offset and transition onset in /∂dud/. An example of the hearing pattern is provided in Figure 4.1 which shows the F2 trajectories for hearing talker H1. Note that both D2 and D3 have lower intelligibility scores than deaf talker D1 who did not show this pattern (instead D1 resembled more the hearing pattern at those measurement points in /∂dud/).

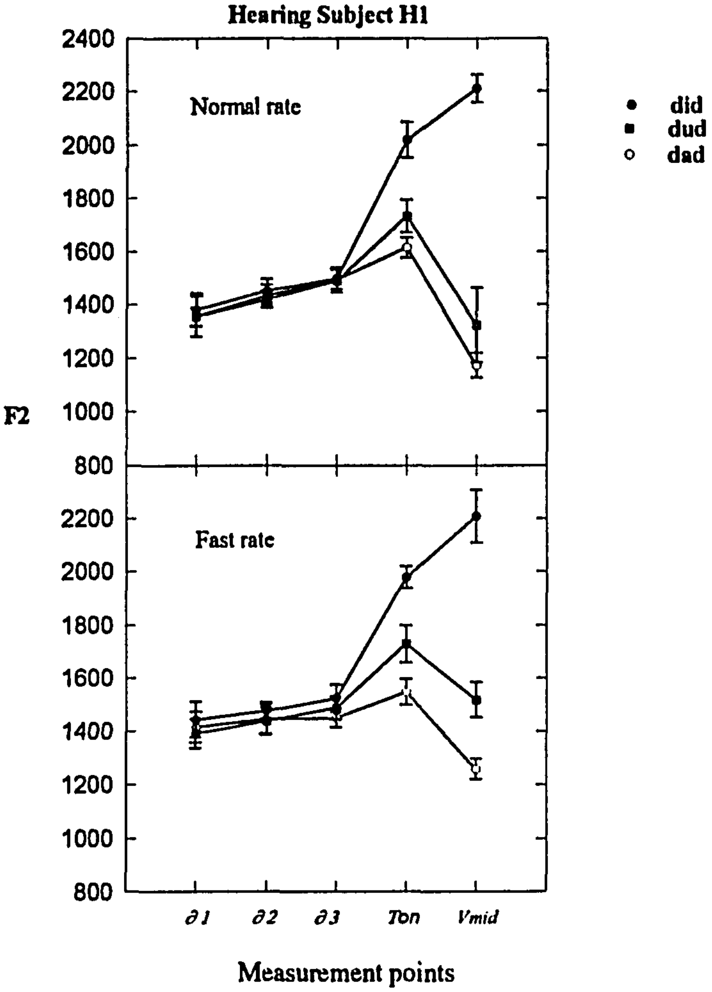


Figure 4.1: Mean F2 at five measurement points along three alveolar disyllables at normal and fast rates for hearing talker H1. The bars show the standard deviation.

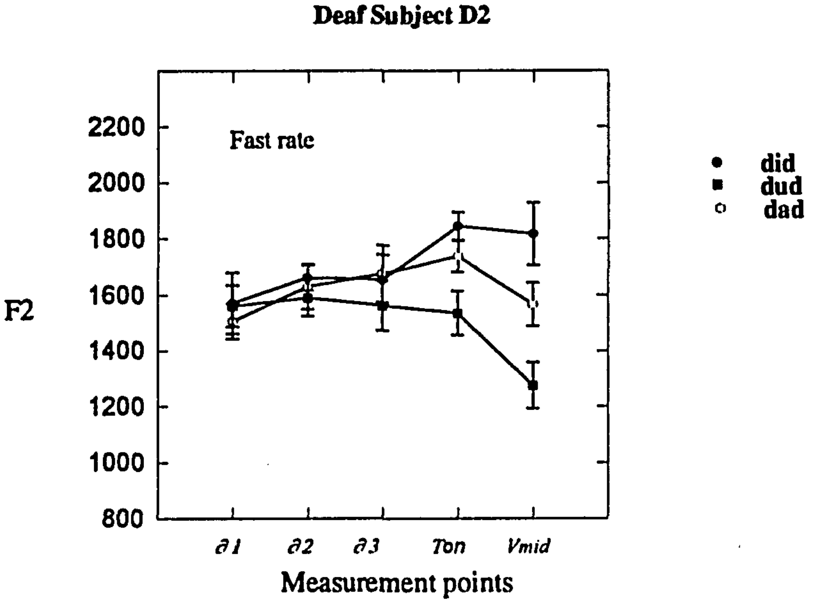


Figure 4.2: Mean F2 at five measurement points along three alveolar disyllables at fast rates for deaf talker D2. The bars show the standard deviation.

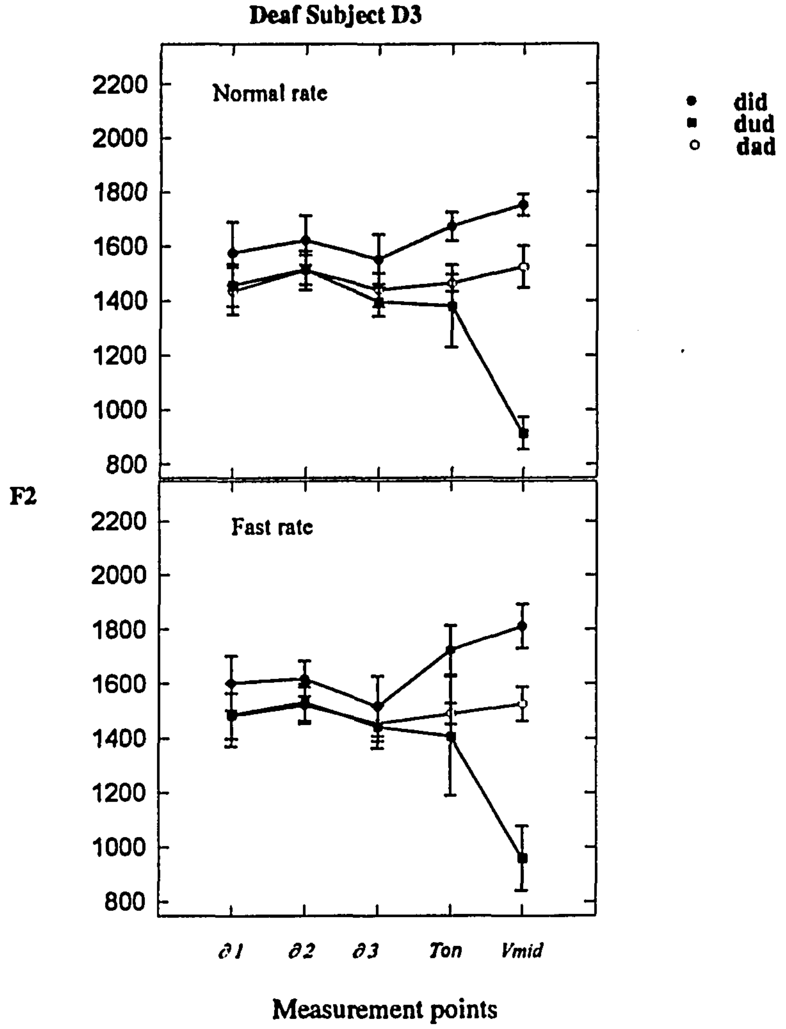


Figure 4.3: Mean F2 at five measurement points along three alveolar disyllables at normal and fast rates for deaf talker D3. The bars show the standard deviation.

It appears that deaf talkers D2 and D3 arrest the carryover effects of the alveolar consonant on the transition onset of /ədud/ by compromising its articulation. It is inferred that they make contact with a flatter tongue posture, as in linguo-dental productions. Thus, it is assumed that these deaf talkers move the jaw up to make a contact following the schwa and, then, during closure or after the consonant release they pull their tongue backwards for the [u] production. This inference is supported by the fact that the deaf talkers have failed to show evidence of anterior movement of the tongue dorsum ([u] as a result of coarticulation with the tongue blade movement for /d/.

Overall, the reduced spectral effects of consonant formation in the deaf vs. the hearing talkers at transition onset for back vowel centers indicate that the deaf talkers articulate the consonants in a less adequate way than the hearing talkers.

d) The deaf talkers have shown reduced or aberrant effects of consonant context on vowel centers, as revealed by the magnitude and direction of F2 shifts at [i],[u],[a] centers in bilabial vs. alveolar contexts.

In this study, the findings on anticipatory coarticulation exhibited by the deaf talkers bear a striking resemblance to the findings for anticipatory coarticulation in developing speech

a) They showed greater anticipatory coarticulation of vowel targets during schwa in alveolar-vowel sequences than the hearing talkers. An important observation on this pattern is that for such sequences both consonant and vowel gestures are articulated by a single articulator, i.e. the tongue. The same results were obtained for developing speech by Nittrouer and her colleagues (Nittrouer, Studdert-Kennedy & McGowan, 1989), that is, children showed greater consonant-vowel overlap than adults in sibilant-vowel sequences, where the tongue's action is responsible for the production of both segments.

b) They showed reduced consonant anticipation effects and a less adequate or compromised consonant articulation (i.e. in D2 and D3 as seen in Figures 4.2-4.3). This conclusion is consistent with developmental studies in coarticulation where children showed less adequate production (and perception) of consonant targets than adults (Nittrouer, Studdert-Kennedy & McGowan 1989; Nittrouer & Studdert-Kennedy, 1987). In a study by Nittrouer, Studdert-Kennedy & McGowan (1989), children's low ratios on centroids at /sV/ vs. /ʃV/ utterances indicated inadequate differentiation of consonant targets. In a study by Nittrouer & Studdert-Kennedy & McGowan (1987), children were not able to discriminate between the /s/ and /ʃ/ centroids as well as adults. In another developmental study on intersegmental coordination in two-year olds, the anticipatory coarticulation was greater at schwa midpoint for adults than 2-year-old children (Goodell & Studdert Kennedy, 1993). This was revealed by smaller mean F2 consonant ratios (1-[C_1V/C_2V]) for children than adults in bi/di, ba/da, bi/gi, ba/ga pairs.

It is concluded that the articulatory organization of deaf talkers resembles that of children. Both the deaf talkers and children show evidence of anticipatory coarticulation of vowel targets because their tongue gestures encompass more than one phone. This form of production compromises consonant articulation because the tongue body movement is not differentiated enough for accurate, time-constrained, phoneme-size production. The same trend with respect to integration of consonant units in running speech has been shown intrasyllabically for the deaf talkers in this study. The F2 shifts within the syllable have indicated reduced or aberrant effects of consonant context on vowel centers. Thus, deaf talker D3 showed nonsignificant F2 shifts of [u] center in bilabial vs. alveolar contexts, whereas the deaf talkers D1 and D2 showed a higher F2 in /bub/ than /dud/. Instead, the hearing talkers in this study have uniformly shown a higher F2 in [u] center in alveolar context, that is, an anterior movement of the tongue dorsum conditioned by coarticulation with the tongue blade. From the above one also concludes that the tongue differentiation into smaller, more independently manageable subarticulatory units such as the tongue blade and the tongue dorsum is a product of gradual maturation of the speech apparatus into phoneme-size production.

The findings in the study are also consistent with Öhman's (1966) account which posits that articulatory organization during running speech involves the concurrent operation of two independent subsystems. Articulatory sequences are planned from vowel-to-vowel with consonant superimpositions controlled by a separate articulatory system. The two accounts (the "primitive speech" account and Öhman's account) are not necessarily in conflict since time-locked constraints of primitive articulatory organization may induce a tighter coproduction of consonant-vowel sequences until the two systems become more independently manageable.

In this study, the pattern of anticipatory vowel articulation yielded different results in relation to hearing status in alveolar vs. bilabial contexts. In bilabial disyllables, where the lips and the tongue coordinate for the production of consonant-vowel sequences respectively, the hearing talkers showed more vowel anticipation than the deaf talkers. This difference diminished only slightly with increased rate. It seems that appropriate coarticulation (or intergestural overlap) between two independent articulators is a skill acquired with maturation and greater refinement of articulatory control in running speech. A similar conclusion was reached by Goodell & Studdert-Kennedy (1993) for bilabial context, when the intergestural consonant-vowel overlap was assessed at vowel onset in adults vs. children. Based on the greater mean F2 vowel indices (1-[Ca/Ci]) for adults than 2-year old children in ba/bi pairs at stressed-vowel onset, they concluded that adults show greater consonant-vowel overlap than children in bilabial-vowel sequences.

Thus, these findings also shed light into the long-standing controversy as to whether coarticulation is an innate or acquired phenomenon. These data support neither simple position. Although the results on intersegmental coordination of the deaf talkers are different from Repp's (1986) data on children, the conclusions in this study conform with Repp's (1986) view that coarticulation is an umbrella term that encompasses many different types of intersegmental coordination. Some types are found in primitive productions and are expected to be reduced with maturation of the articulatory apparatus whereas other types require fine motor control. In our account, which accords with the Goodell & Studdert-Kennedy (1993) study, primitive coarticulatory patterns can be found in intrarticulatory coordination between segments whereas mature coarticulatory patterns can be found in interarticulatory coordination between segments.

4.8 IMPLICATIONS FOR FUTURE RESEARCH

The results of the acoustic analyses in intersegmental patterning in deaf vs. hearing talkers offer some suggestions for future research. Several types of studies can be conducted to throw more light into the existing findings. An acoustic study can be conducted to examine the spectral differences between the consonants of deaf vs. hearing talkers. The frequency of the burst and the VOT values in /ədVd/ disyllables can be compared across talkers that differ in hearing status and age. This may determine whether the consonant productions of deaf talkers and children are similar to each other and different from the normal adults'. Furthermore, a longitudinal acoustic study in the development of intersegmental coordination in orally-trained deaf talkers may throw further light into whether their speech is developmentally primitive or a product of teaching.

Physiological studies would also help by allowing direct observation of the articulatory patterns inferred from the acoustic results of the present study. Specific physiological techniques can be used to verify the different findings of this study. The palatometer enables the study of tongue contacts on the palate, thus, a palatographic study on alveolar-vowel sequences in deaf and hearing adult talkers may determine whether the size and location of alveolar tongue contacts is different in the two groups. An LED (Light Emitting Diodes) kinematic analysis, on the other hand, may reveal information about the timing patterns among different (sub)articulatory systems. A kinematic study comparing productions of /∂bVb/ and /∂dVd/ in deaf and the hearing talkers, which are tracked via attached light emitting diodes on the lips, tongue blade and tongue dorsum, may reveal further details about the differences in intra- and interarticulatory coordination as a function of hearing status.

4.9 GENERALIZABILITY OF THE DATA

A single subject design with replications is a standard design used for the study of behavior. Not all patterns observed in this study were generalizable. There were substantial inter-subject differences among the deaf talkers with respect to a) the effects of consonant context on vowel centers within the syllable, b) the temporal extent of anticipatory coarticulation of vowel centers in each context and c) the temporal extent of anticipatory coarticulation of consonant targets.

However, while the total number of subjects in this study is small, it can be seen that the central conclusions on anticipatory coarticulation of vowel and consonant targets are repeated for each subject in each group (i.e. three talkers). Thus, in alveolar contexts, the deaf talkers showed greater anticipatory coarticulation of vowel centers than the hearing talkers. In in bilabial contexts, the hearing talkers showed greater anticipatory coarticulation of vowel centers than the the deaf talkers. Furthermore, the hearing talkers showed greater anticipatory coarticulation of consonant context than the deaf talkers.

Caution should be exercised, however, in generalizing these findings to the deaf talkers that differ in degree of hearing loss, type of oral training and age of onset of deafness. The deaf talkers in this study had a very profound hearing loss (PTA =107+ dB HL) and were orally trained at Clarke School of the Deaf, using an approach that emphasizes the production of whole syllables. Also, they were all prelingually deaf, possibly at birth. It is expected that deaf talkers with similar characteristics and background would show similar patterns of intersyllabic coordination to those seen in this study.

With regard to generalization, it should be noted here that the performance of deaf talker D1 in the word recognition (13% of words recognized) and speech intelligibilty tests (46% of words understood by listeners) was considerably better than that of the other two deaf talkers. The question that arises is: Does deaf talker D1 show coarticulatory patterns that resemble more the hearing pattern than the other deaf talkers? Indeed, in one instance, deaf talker D1, showed a similar pattern to the hearing talkers. He exhibited increases in anticipatory coarticulation of vowel centers in bilabial contexts as a function of increased rate. However, the rest of the D1's patterns resembled the ones seen in at least one of the other two deaf talkers. Thus, there is some slight suggestion in these data that the coarticulatory patterns of the deaf talkers covary with intelligibility.

4.10 CLINICAL APPLICATION

The findings of this study point to some directions with respect to the oral rehabilitation of deaf persons. The deaf talkers in this study had difficulty coordinating the movements of two separate articulators in running speech (see anticipatory coarticulation in bilabial productions). Hence, emphasis should be placed in oral-motor exercises and trills which involve movement of two articulators. With respect to the clinical application of using a faster speaking rate, findings indicate that such a method might facilitate appropriate production in cases where the intersegmental coordination is somewhat established, as in alveolar disyllables. However, inappropriate increases in rate might cause an increase of aberrant patterns of movement.

It should be noted that all the deaf talkers in this study were trained via the syllabic approach to speech. One can not rule out the effects of such training in the patterns observed. Whether production in greater than phoneme-size units is partly a product of training or purely an innate process for certain types of speech utterances (i.e. alveolar context), the results of this study generally suggest that methods that emphasize training in longer speech units should be encouraged in the speech training of deaf individuals. Teaching emphasis on coproduction involving two separate articulators might alleviate the difficulties noted in coordination of lip-tongue movement. These results further suggest that speech training models might also incorporate a) teaching in CV or VCV units with a higher emphasis on the spatio-temporal accuracy of consonant productions b) more elaborate sequences of duplicated syllables (CVCV) which contrast alternatively in consonant and vowel context.

The suggestion for syllabically-structured rather than phone-by-phone modeling, although different in reasoning, is in general conformity with Hudgins'

(1937; 1946) and Ling's (1976) plans for teaching speech by oral means to individuals with hearing loss. Hudgins (1946) has emphasized that no attempt should be made to teach specific sounds until a regular pattern of CV-like vocalizations is established for communication.

APPENDIX A

3 x 3 two -way Anovas (__cost'.sta)

Hearing talkers:

Three 3x3 factorial analyses of variance were performed, each on the token data of a single hearing talker. F2 values at the vowel midpoint were analyzed as a function of consonant condition (context-free vs. bilabial vs. alveolar) and vowel type ([a], [i] and [u]). As seen below, all hearing talkers showed significant main effects for consonant condition and vowel type and a significant interaction between consonant condition and vowel type.

The summary of analysis for talker H1 is reported in table A1.

TABLE A1: SUMMARY TABLE; H1

Source	df	MS effect	df Error	MS Error	F	p-level
CC	2	175642.	81	4519.262	38.865	.000000 [25]
V	2	12616899	81	4519.262	2791.805	.000000
CCxV	4	289839	81	4519.262	64.134	.000000

[25] Throughout the appendices a p=.000000 indicates that the p level is smaller than .0000001.

The main effect of consonant condition (CC) was statistically significant (F=38.865, df=2, p<.000000). A comparison among the means of the three consonant conditions indicated that the alveolar condition is higher than the bilabial and context-free condition (alveolar= 1657 Hz). The mean F2 for the bilabial condition was lowest, equal to 1416 Hz. The mean F2 for the context-free condition lay in between the two embedded conditions and was 1509 Hz.

The main effect of vowel type was also statistically significant (F=2791.81, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel [i] has the highest F2 (2239 Hz) and vowel [u] has the lowest F2 (1037). This finding was as expected.

The interaction of consonant condition by vowel type was also significant (F=64.134, df=4, p<.000000). The pairs of consonant conditions that had different F2 values for the same vowel varied along vowel type. The particular consonant x vowel interactions have been discussed in the text (section 3.1).

The summary of analysis for talker H2 is reported in table A2.

TABLE A2: SUMMARY TABLE; H2

Source	**df**	**MS effect**	**df Error**	**MS Error**	**F**	**p-level**
CC	2	207415	81	2607.767	79.537	.000000
V	2	9663673	81	2607.767	3705.728	.000000
CCxV	4	121733	81	2607.767	46.681	.000000

The main effect of consonant condition (CC) was statistically significant (F=79,54 df=2, p<.000000). A comparison among the means of the three consonant conditions indicated that the alveolar condition is higher than the bilabial and context-free condition (embedded-dd= 1700 Hz). The mean F2 for the bilabial condition was lowest, equal to 1544 Hz. The mean F2 for the context-free condition lay in between the two embedded conditions and was very close in value to the bilabial condition 1573 Hz.

The main effect of vowel type was also statistically significant (F=3705.73, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel [i] has the highest F2 (2261 Hz). Vowels [a] and [u] showed similar F2 mean values, as averaged across consonant conditions ([a]= 1272 Hz, [u]=1284 Hz).

The interaction of consonant condition by vowel type was also significant (F=46.681, df=4, p< .000000). The particular consonant x vowel interactions have been discussed in text (section 3.1).

The summary of analysis for talker H3 is reported in table A3.

TABLE 5: SUMMARY TABLE; H3

Source	**df**	**MS effect**	**df Error**	**MS Error**	**F**	**p-level**
CC	2	349584	81	1513.828	230.927	.000000
V	2	7801857	81	1513.828	5153.726	.000000
CCxV	4	353109	81	1513.828	233.255	.000000

The main effect of consonant condition (CC) was statistically significant (F= 230.927, df=2, p<.000000). A comparison among the means of the three consonant conditions indicated that the alveolar condition is higher than the bilabial and context-free condition (embedded-dd=1665 Hz). The mean F2 for the bilabial condition was lowest, equal to 1462 Hz. The mean F2 for the context-free condition lay in between the two embedded conditions and was very close in value to the bilabial condition 1500 Hz.

The main effect of vowel type was also statistically significant (F= 5153.726, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel [i] has the highest F2 (2131 Hz). Vowels [a] and [u] showed similar F2 mean values, as averaged across consonant conditions ([a]= 1266 Hz, [u]=1231 Hz) with [u] being lowest.

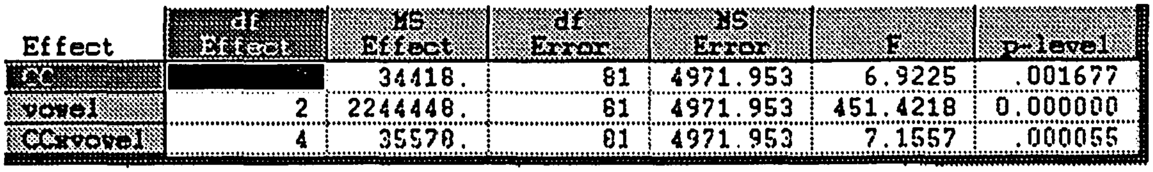
The interaction of consonant condition by vowel type was also significant (F=233.255, df=4, p< .000000). The particular consonant x vowel interactions have been discussed in text (section 3.1).

Deaf talkers:

Three 3x3 factorial analyses of variance were performed, each on the token data of a single deaf talker. F2 values at the vowel midpoint were analyzed as a function of consonant condition (context-free vs. bilabial vs. alveolar) and vowel type ([a], [i] and [u]). As seen below, all deaf talkers showed significant main effects for consonant condition and vowel type and a significant interaction between consonant condition and vowel type.

The summary of analysis for talker D1 is reported in table A4.

TABLE A4: SUMMARY TABLE; D1



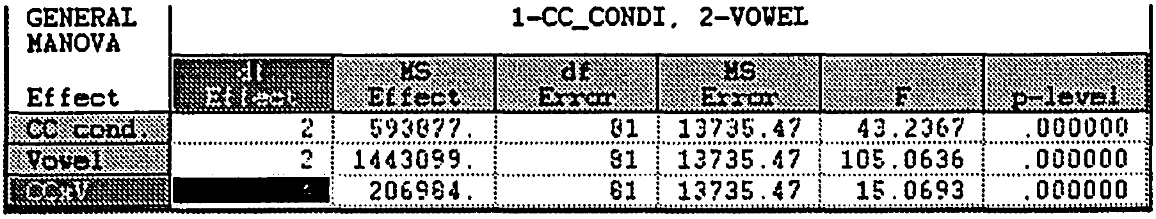
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
CC	[illegible]	34418.	81	4971.953	6.9225	.001677
vowel	2	2244448.	81	4971.953	451.4218	0.000000
CCxvowel	4	35578.	81	4971.953	7.1557	.000055

The main effect of consonant condition (CC) was statistically significant (F=6.9223, df=2, p<.001677). A comparison among the means of the three consonant conditions averaged across vowels indicated that the bilabial condition is higher than the alveolar and context-free condition (embedded-bb=1550 Hz). The mean F2 for the alveolar condition (1495 Hz) was equal to the context-free condition (1497 Hz).

The main effect of vowel type was also statistically significant (F=451.422, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel [i] has the highest F2 (1769 Hz) and vowel [a] has the lowest F2 (1226 Hz). Note that vowel [u] averaged higher than vowel center [a], 1553 Hz. The interaction of consonant condition by vowel type was also significant (F=7.156, df=4, p<.000055). This interaction has been discussed in detail in the text (section 3.1).

The summary of analysis for talker D2 is reported in table A5.

TABLE A5: SUMMARY TABLE; D2



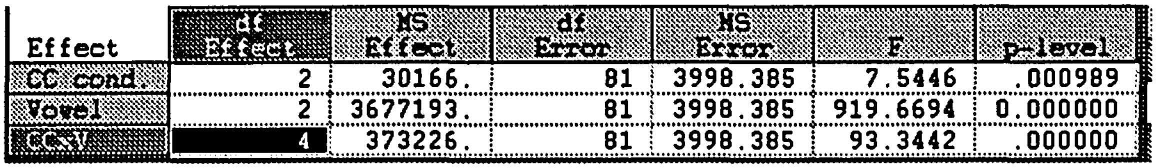
GENERAL MANOVA	1-CC_CONDI, 2-VOWEL					
Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
CC cond.	2	593077.	81	13735.47	43.2367	.000000
Vowel	2	1443099.	81	13735.47	105.0636	.000000
CCxV	4	206984.	81	13735.47	15.0693	.000000

The main effect of consonant condition (CC) was statistically significant (F=43.24, df=2, p<.000000). A comparison among the means of the three consonant conditions averaged across vowels indicated that the bilabial condition is higher than the alveolar and context-free condition (embedded-bb=1656 Hz). The mean F2 for the alveolar condition (1567 Hz) is higher than the context-free condition (1380 Hz).

The main effect of vowel type was also statistically significant (F=105.064, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel center [i] has the highest F2 (1782 Hz) and vowel center [u] has the lowest F2 (1363 Hz). Vowel center [a] averaged at 1459 Hz. The interaction of consonant condition by vowel type was also significant (F=15.6093, df=4, p<.000000) (see discussion in text, section 3.1).

The summary of analysis for deaf talker D3 is reported in table A6.

TABLE A6: SUMMARY TABLE; D3



Effect	df Effect	MS Effect	df Error	MS Error	F	p-level
CC cond.	2	30166.	81	3998.385	7.5446	.000989
Vowel	2	3677193.	81	3998.385	919.6694	0.000000
CCxV	4	373226.	81	3998.385	93.3442	.000000

The main effect of consonant condition (CC) was statistically significant (F=7.545, df=2, p<.000989). A comparison among the means of the three consonant conditions averaged across vowels indicated that the isolated (1415 Hz) condition is higher than the alveolar (1395 Hz) and bilabial (1353 Hz) conditions. Also, the alveolar condition is slightly higher than the context-free condition.

The main effect of vowel type was also statistically significant (F=919.67, df=2, p<.000000). A comparison of F2 means among the three vowel types as averaged across consonant conditions indicated that vowel center [i] has the highest F2 (1721 Hz) and vowel center [u] has the lowest F2 (1023 Hz). Vowel center [a] averaged at 1418 Hz. The interaction of consonant condition by vowel type was also significant (F=93.344, df=4, p<.000000), see discussion in text (section 3.1).

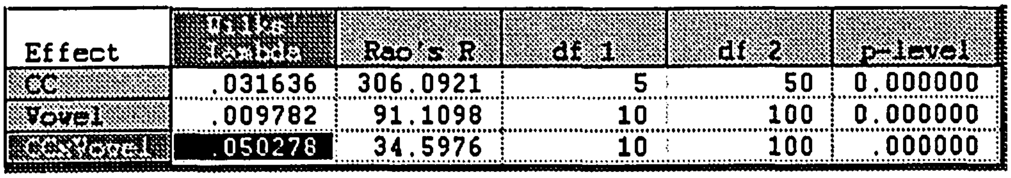
APPENDIX B

1. COARTICULATION IN DISYLLABLES – Coarticulation of vowel context.

HEARING TALKER H1

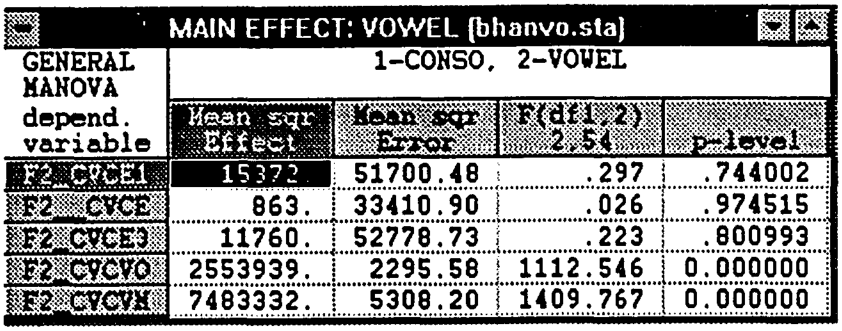
A 2x3 multivariate factorial analysis was performed on the token data of talker H1. F2 values at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint were analyzed as a function of consonant environment (bilabial vs. alveolar) and vowel type ([a], [i], [u]). The results relevant to anticipatory coarticulation of vowel constrictions are discussed below (see Tables B1, B1.2 and B1.3).

TABLE B1: SUMMARY TABLE; H1



Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
CC	.031636	306.0921	5	50	0.000000
Vowel	.009782	91.1098	10	100	0.000000
CC*Vowel	.050278	34.5976	10	100	.000000

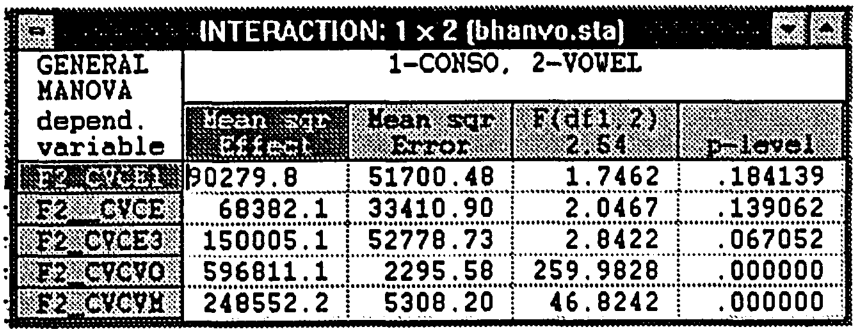
TABLE B1.2: MAIN EFFECT OF VOWEL; H1



MAIN EFFECT: VOWEL (bhanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	15372	51700.48	.297	.744002
F2_CVCE	863.	33410.90	.026	.974515
F2_CVCE3	11760.	52778.73	.223	.800993
F2_CVCVO	2553939.	2295.58	1112.546	0.000000
F2_CVCVM	7483332.	5308.20	1409.767	0.000000

TABLE B1.3: CONSONANT BY VOWEL INTERACTION; H1



INTERACTION: 1 x 2 (bhanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	90279.8	51700.48	1.7462	.184139
F2_CVCE	68382.1	33410.90	2.0467	.139062
F2_CVCE3	150005.1	52778.73	2.8422	.067052
F2_CVCVO	596811.1	2295.58	259.9828	.000000
F2_CVCVM	248552.2	5308.20	46.8242	.000000

As clearly seen the Wilks' lamda (Table B1) was significant for the main effect of vowel and the consonant x vowel interaction. Univariate analysis showed that the main effect of vowel (Table B1.2) is significant at vowel onset and vowel midpoint only. Univariate analysis showed that the consonant x vowel interaction (Table B1.3) is significant at vowel onset and vowel midpoint only.

The above consonant x vowel interaction was examined via planned comparisons, using the Bonferroni correction, at Table B1.4. Planned comparisons were performed on six disyllable pairs, containing all consonant-vowel combinations.

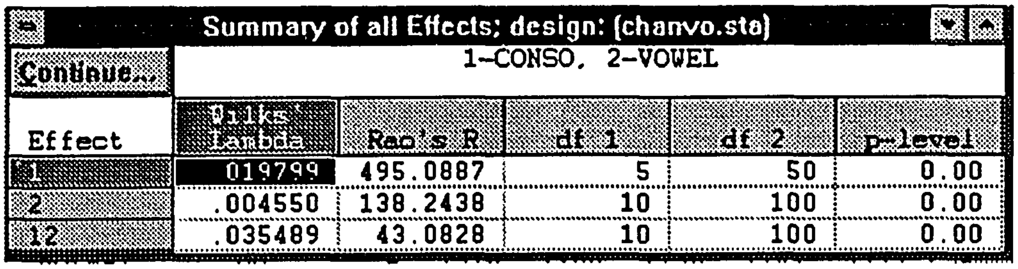
TABLE B1.4 : Planned Comparisons ; H1

Comparison	**∂1**	**∂2**	**∂3**	**T onset**	**V mid**
/∂bib/>/∂bab/	F=5.375, p<.024316	F=14.809, p<.000322*	F=9.946, p<.000000*	F=1450.268, p<.000000*	F=993.626 p<.000000*
/∂bib/>/∂bab/	F=3.540, p<.065415	F=11.296, p<.001446*	F=8.216, p<.005943	F=2092.425, p<.000000*	F=1506.102, p<.000000*
/∂bab/>/∂bub/	F=.2589 p<872782	F=3.42123 p<..069942	F=16.953 p<.682193	F=58.6856 p<.000000*	F=53.0960 p<.000000*
/∂did/>/∂dad/	F=1.050 p<.310	F=2.137 p<.1496	F=1.719 p<..1954	F=357.263 p<.000000*	F=1016.842 p<.000000*
/∂did/>/∂dud/	F=1.0141 p<.3184	F=1.6217 p<.2083	F=1.6332 p<.2067	F=178.1598 p<.000000*	F=744.936 p<.000000*
/∂dud/>/∂dad/	F=0.00031 p<.986	F=0.0355 p<.8513	F=0.0011 p<.9737	F=30.844 p<.000001*	F=21.109 p<.000026*

HEARING TALKER H2

A 2x3 multivariate factorial analysis was performed on the token data of talker H2. F2 values at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint were analyzed as a function of consonant environment (bilabial vs. alveolar) and vowel type ([a], [i], [u]). The results relevant to anticipatory coarticulation of vowel constrictions are discussed below (see Tables B2, B2.2 and B2.3).

TABLE B2: SUMMARY TABLE; H2

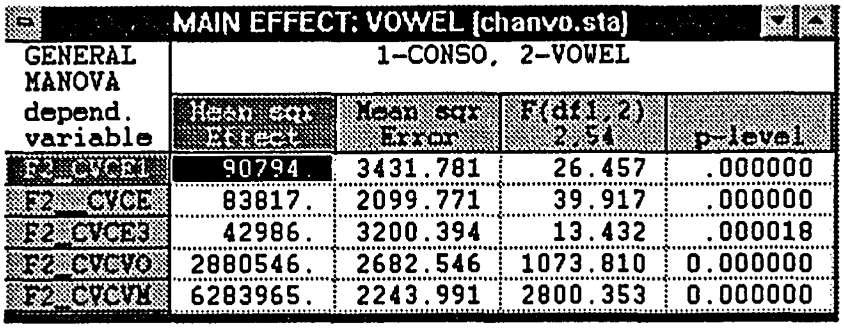


Summary of all Effects; design: (chanvo.sta)

1-CONSO, 2-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
1	.019799	495.0887	5	50	0.00
2	.004550	138.2438	10	100	0.00
12	.035489	43.0828	10	100	0.00

TABLE B2.2: MAIN EFFECT OF VOWEL; H2

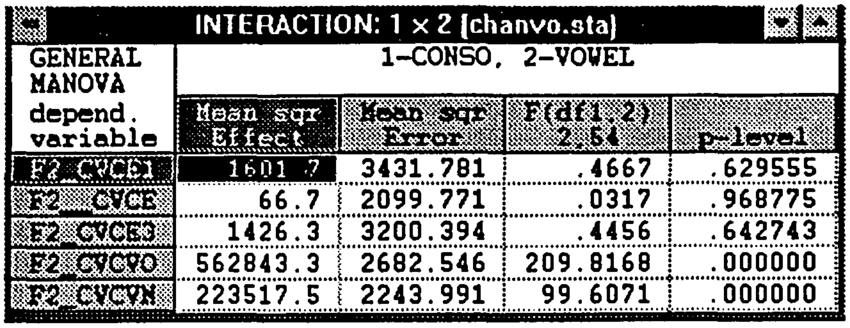


MAIN EFFECT: VOWEL (chanvo.sta)

1-CONSO, 2-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
[illegible]	90794.	3431.781	26.457	.000000
F2__CVCE	83817.	2099.771	39.917	.000000
F2_CVCE3	42986.	3200.394	13.432	.000018
F2_CVCVO	2880546.	2682.546	1073.810	0.000000
F2_CVCVM	6283965.	2243.991	2800.353	0.000000

TABLE B2.3: CONSONANT X VOWEL INTERACTION; H2



INTERACTION: 1 x 2 (chanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	1601.7	3431.781	.4667	.629555
F2_CVCE	66.7	2099.771	.0317	.968775
F2_CVCE3	1426.3	3200.394	.4456	.642743
F2_CVCVO	562843.3	2682.546	209.8168	.000000
F2_CVCVN	223517.5	2243.991	99.6071	.000000

As seen, the Wilks' lamda (Table B2) indicated significant results for the main effect of vowel and the consonant x vowel interaction. Univariate analysis showed significant vowel main effects (Table B2.2) across all five measurement points of the disyllables, collapsed over bilabial/alveolar consonant environment. Univariate analysis also indicated that the consonant x vowel interaction (Table B2.3) is significant at vowel onset and vowel midpoint only.

The above interaction was examined via planned comparisons (see Table B2.4). The consonant x vowel interaction at vowel onset will be also discussed in "anticipatory coarticulation of consonant context".

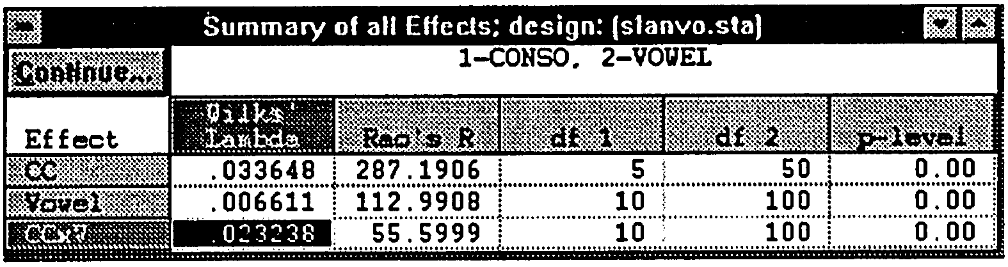
TABLE B2.4: Planned Comparisons; H2

Comparison	**∂1**	**∂2**	**∂3**	**T onset**	**V mid**
/∂bib/>/∂bab/	F=23.722 p<.000010*	F=30.030, p<.000001*	F=10.454, p<.00209*	F=1712.407, p<.000000*	F=2266.213, p<.000000*
/∂bib/>/∂bub/	F=17.758, p<.000096*	F=29.870, p<.000001*	F=9.726, p<.002913*	F=1518.832, p<.000000*	F=2884.568, p<.000000*
/∂bab/>/∂bub/	F=431.03 p<.514	F=.00021 p<.988	F=0.1314 p<.9091	F=5.804 p<.0194	F=37.2517 p<.000000*
/∂did/>/∂dad/	F=16.155 p<.000182*	F=31.931 p<.000001*	F=14.041 p<.000437	F=407.367 p<.000000*	F=2127.291 p<.000000*
/∂did/>/∂dud/	F=22.222 p<.000017*	F=27.877 p<.000002*	F=5.328 p<.024839	F=127.068 p<.000000*	F=1276.515 p<.000000*
/∂dud/>/∂dad/	F=0.4826 p<.490222	F=0.1375 p<.712191	F=2.0700 p<.155993	F=79.4040 p<.000001*	F=108.0397 p<.000000*

HEARING TALKER H3

A 2x3 multivariate factorial analysis was performed on the token data of talker H3. F2 values at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint were analyzed as a function of consonant environment (bilabial vs. alveolar) and vowel type ([a], [i], [u]). The results relevant to anticipatory coarticulation of vowel constrictions are discussed below (see Tables B3, B3.2 and B3.3).

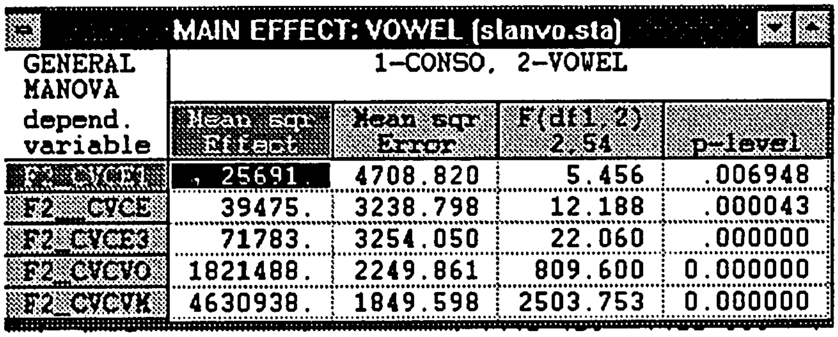
TABLE B3: SUMMARY TABLE; H3



1-CONSO, 2-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
CC	.033648	287.1906	5	50	0.00
Vowel	.006611	112.9908	10	100	0.00
CC×V	.023238	55.5999	10	100	0.00

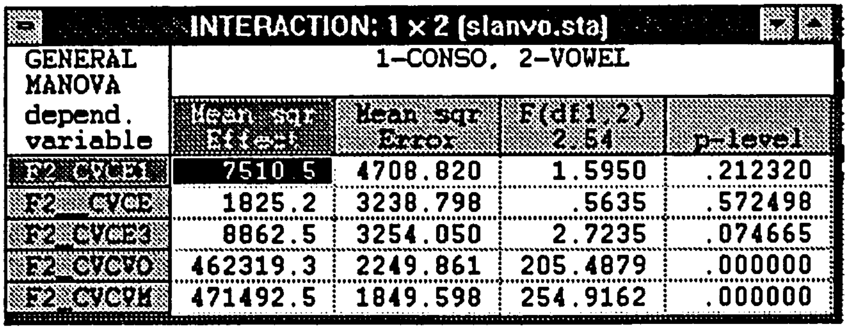
TABLE B3.2: MAIN EFFECT OF VOWEL; H3.



1-CONSO, 2-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	25691.	4708.820	5.456	.006948
F2_CVCE	39475.	3238.798	12.188	.000043
F2_CVCE3	71783.	3254.050	22.060	.000000
F2_CVCVO	1821488.	2249.861	809.600	0.000000
F2_CVCVK	4630938.	1849.598	2503.753	0.000000

TABLE B3.3: CONSONANT BY VOWEL INTERACTION; H3



1-CONSO, 2-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	7510.5	4708.820	1.5950	.212320
F2_CVCE	1825.2	3238.798	.5635	.572498
F2_CVCE3	8862.5	3254.050	2.7235	.074665
F2_CVCVO	462319.3	2249.861	205.4879	.000000
F2_CVCVM	471492.5	1849.598	254.9162	.000000

As seen above, the Wilks' lamda revealed a significant main effect for the vowel as well as significant consonant x vowel interactions. Univariate analysis showed significant main effects of vowel at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint. Also, the consonant x vowel interaction was significant at the vowel onset and vowel midpoint only. Planned comparisons, in Table B3.4, examined the above interaction.

TABLE B3.4: Planned Comparisons; H3

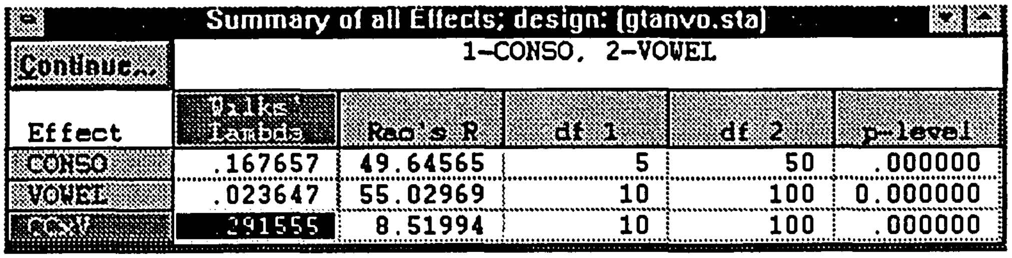
Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=10.555 p<.001996*	F=13.991, p<.000446*	F=29.688, p<.000001*	F=1242.42, p<.000000*	F=2142.72 p<.000000*
/∂bib/>/∂bub/	F=8.411, p<.005384*	F=6.909, p<.011143*	F=21.467, p<.000023*	F=1311.82, p<.000000*	F=3095.0, p<.000000*
/∂bab/>/∂bub/	F=121.57 p<.728694	F=1.2364 p<.271092	F=0.6648 p<.418462	F=0.9431 p<.335817	F=87.295 p<.000000*
/∂did/>/∂dad/	F=1.376 p<.245908	F=10.456 p<.002087*	F=14.577 p<.000349*	F=324.63 p<.000000*	F=1935.24 p<.000000*
/∂did/>/∂dud/	F=.3793 p<.540566	F=1.3253 p<.254711	F=1.7762 p<.188207	F=60.211 p<.000000*	F=723.678 p<.000000*
/∂dud/>/∂dad/	F=0.3105 p<.579681	F=4.3365 p<.042056	F=6.1762 p<.0.16077	F=105.23 p<.000001*	F=292.07 p<.000000*

Planned comparisons indicated that the significant vowel main effects at schwa onset, schwa midpoint, schwa offset and vowel onset are attributed mostly to bilabial context.

DEAF TALKER D1

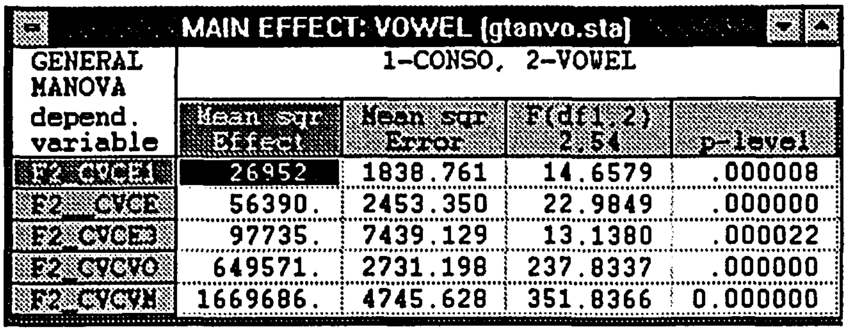
A 2x3 multivariate factorial analysis was performed on the token data of talker D1. F2 values at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint were analyzed as a function of consonant environment (bilabial vs. alveolar) and vowel type ([a], [i], [u]). The results relevant to anticipatory coarticulation of vowel constrictions are discussed below (see Tables B4, B4.2 and B4.3).

TABLE B4: SUMMARY TABLE; D1



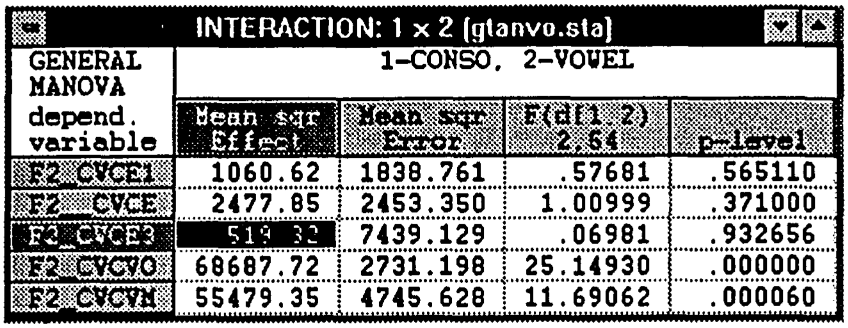
Effect	1-CONSO, 2-VOWEL Wilks' Lambda	Rao's R	df 1	df 2	p-level
CONSO	.167657	49.64565	5	50	.000000
VOWEL	.023647	55.02969	10	100	0.000000
[illegible]	.291555	8.51994	10	100	.000000

TABLE B4.2: MAIN EFFECT OF VOWEL; D1



GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	26952	1838.761	14.6579	.000008
F2__CVCE	56390.	2453.350	22.9849	.000000
F2_CVCE3	97735.	7439.129	13.1380	.000022
F2_CVCVO	649571.	2731.198	237.8337	.000000
F2_CVCVM	1669686.	4745.628	351.8366	0.000000

TABLE B4.3: CONSONANT BY VOWEL INTERACTION; D1



INTERACTION: 1 x 2 (gtanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,64	p-level
F2_CVCE1	1060.62	1838.761	.57681	.565110
F2__CVCE	2477.85	2453.350	1.00999	.371000
F2_CVCE3	519.32	7439.129	.06981	.932656
F2_CVCVO	68687.72	2731.198	25.14930	.000000
F2_CVCVM	55479.35	4745.628	11.69062	.000060

The results of multivariate analysis indicated significant main effects for the vowel and the consonant x vowel interaction. The Wilks' lamda was highly significant (see Table B4). Univariate analysis indicated that the vowel main effect was highly significant (p<.00001) across all measurement points. Univariate analysis has also indicated that the consonant x vowel interaction is highly significant at vowel onset and vowel midpoint only (see Table B4.3). Since such interaction was not significant at the schwa parts, one concludes that disyllables with contrasted vowels, collapsed across consonant context, show significant anticipation effects as early as the schwa onset, for talker D1.

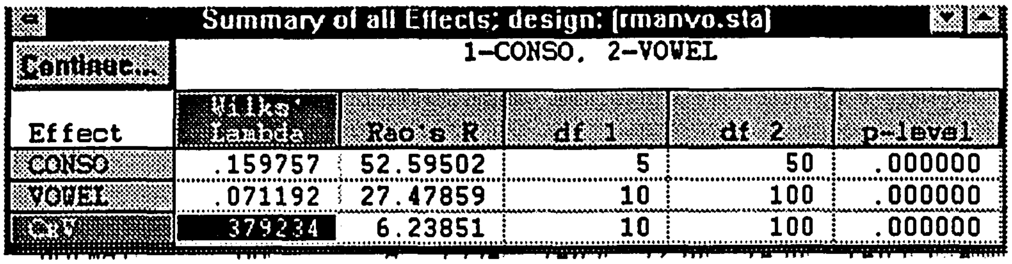
TABLE B4.4 : Planned Comparisons; D1

Comparison	**∂1**	**∂2**	**∂3**	**T onset**	**V mid**
/∂bib/>/∂bab/	F=9.6267, p<.00305*	F=21.9163, p<.000020*	F=12.4865, p<.00085*	F=350.568, p<.000000*	F=409.064, p<.000000*
/∂bib/>/∂bub/	F=2.698, p<.106276	F=00.4344, p<.512626	F=0.67968, p<..413325	F=5.5178, p<.022513	F=34.823, p<.000000*
/∂bab/</∂bub/	F=2.1319 p<.150058	F=16.1795 p<.000180*	F=7.3397 p<.009018	F=268.123, p<.000000*	F=205.18, p<.000000*
/∂did/>/∂dad/	F=20.393 p<.000035*	F=22.2984 p<.000017*	F=12.4316 p<..000869*	F=99.814 p<.000000*	F=292.84 p<.000000*
/∂did/>/∂dud/	F=8.0176 p<.0065	F=5.8552 p<.206675	F=1.63358 p<.20668	F=5.0844 p<.028219	F=92.50 p<.000000*
/∂dud/>/∂dad/	F=2.837 p<.097892	F=5.301 p<.025196	F=5.05226 p<028700	F=59.843 p<.000000*	F=56.173 p<.000000*

DEAF TALKER D2

A 2x3 multivariate analysis indicated a significant Wilks' lamda (Table B5) for the main effect of vowel and a significant consonant x vowel interaction (Table B5.3). Univariate results revealed significant F ratios for the main effect of vowel for schwa midpoint, schwa offset, vowel onset and vowel midpoint. Also, univariate results have shown significant F ratios for consonant x vowel interactions at vowel onset and vowel midpoint. The consonant x vowel interaction refers to the higher F2 means for /ðbub/ than /ðbab/ and the lower F2 means for /ð dud/ than /ðdad/, at vowel onset and vowel midpoint.

TABLE B5: SUMMARY TABLE; D2

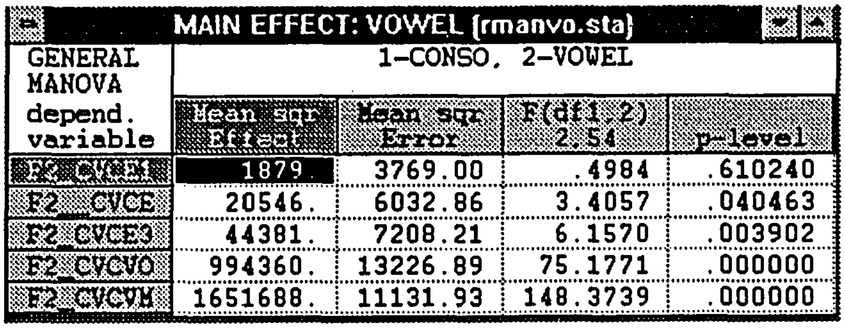


Summary of all Effects; design: (rmanvo.sta)

1-CONSO, 2-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
CONSO	.159757	52.59502	5	50	.000000
VOWEL	.071192	27.47859	10	100	.000000
[illegible]	379234	6.23851	10	100	.000000

TABLE B5.2: MAIN EFFECT OF VOWEL; D2

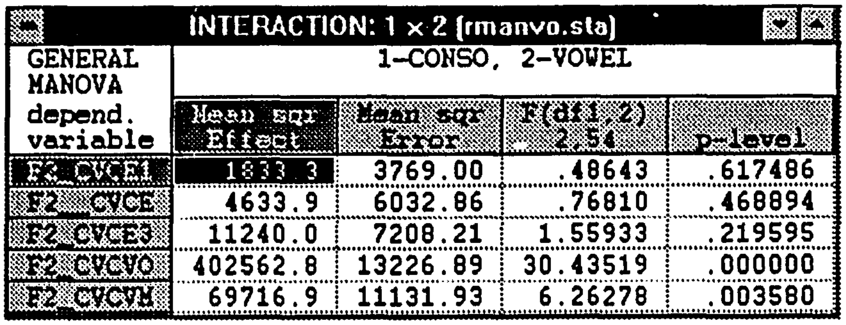


MAIN EFFECT: VOWEL (rmanvo.sta)

1-CONSO, 2-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
[illegible]	1879.	3769.00	.4984	.610240
F2_CVCE	20546.	6032.86	3.4057	.040463
F2_CVCE3	44381.	7208.21	6.1570	.003902
F2_CVCVO	994360.	13226.89	75.1771	.000000
F2_CVCVM	1651688.	11131.93	148.3739	.000000

TABLE B5.3: CONSONANT BY VOWEL INTERACTION; D2



GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	1833.3	3769.00	.48643	.617486
F2_CVCE	4633.9	6032.86	.76810	.468894
F2_CVCE3	11240.0	7208.21	1.55933	.219595
F2_CVCVO	402562.8	13226.89	30.43519	.000000
F2_CVCVM	69716.9	11131.93	6.26278	.003580

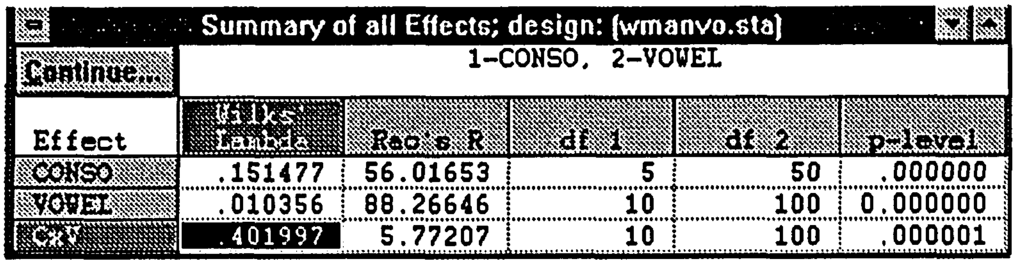
TABLE B5.4 : Planned Comparisons; D2

Comparison	*∂1*	*∂2*	*∂3*	**T onset**	**V mid**
/∂bib/>/∂bab/	F=0.1327, p<.717111	F=0.9190, p<.3411	F=4.2310, p<.044536	F=172.592, p<.000000*	F=104.91, p<.000000*
/∂bib/>/∂bub/	F=0.15188, p<.698274	F=0.00697, p<.933773	F=7.79389, p<.007234	F=30.00, p<.000001*	F=81.51, p<.000000*
/∂bab/</∂bub/	F=0.00065 p<.979763	F=0.76594 p<.385353	F=75.3995 p<.465634	F=58.682 p<.000000*	F=1.47 p<.2299
/∂did/>/∂dad/	F=0.50444 p<.48061	F=7.19911 p<.009661	F=0.13596 p<.713777	F=14.88 p<.000308*	F=94.012 p<.000000*
/∂did/>/∂dud/	F=0.3879 p<.53602	F=1.4830 p<.228607	F=4.3841 p<.040986	F=36.0702 p<.000000*	F=170.66 p<.000000*
/∂dad/>/∂dud/	F=1.77708 p<.188106	F=2.14725 p<.148624	F=6.06409 p<017017	F=4.61569 p<.036183	F=11.341 p<.001404*

DEAF TALKER D3

A 2x3 multivariate factorial analysis revealed a highly significant Wilks' lamda for the main effect of vowel and the consonant x vowel interaction (see Table B6). Univariate results indicated that the vowel main effect, as averaged across consonant type, is significant for all measurement points in the disyllable. Also, univariate results indicated that consonant by vowel interactions are significant at schwa onset, schwa midpoint, schwa offset and vowel onset (Table B6.3). This interaction becomes explicitly obvious when one reviews Table B6.4 shows earlier anticipation in D3 for alveolar than bilabial disyllables (note that the earlier anticipation in /əbub/-/əbab/ than /ədud/-/ədad/ is due to anticipation of the consonant /b/ than the vowel centers). Also, at vowel onset the F2 means are significantly different for /əbub/-/əbab/ but only nearly significant for /ədud/-/ə dad/.

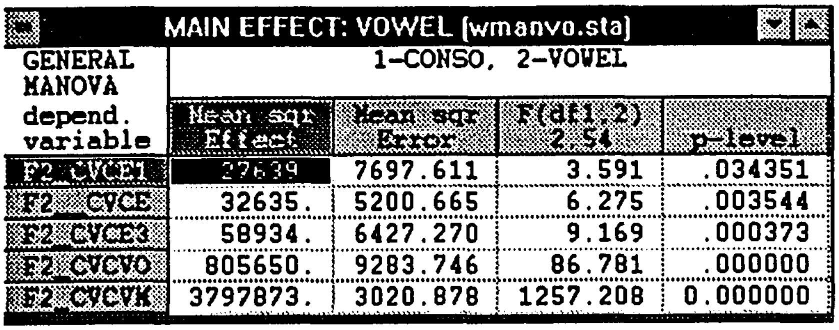
TABLE B4: SUMMARY TABLE; D3



1-CONSO, 2-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
CONSO	.151477	56.01653	5	50	.000000
VOWEL	.010356	88.26646	10	100	0.000000
CxV	.401997	5.77207	10	100	.000001

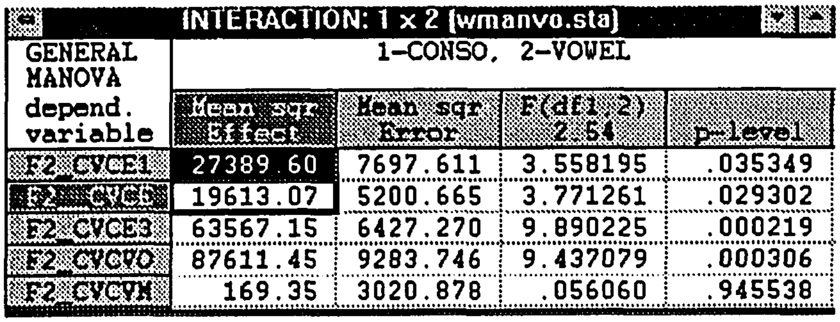
TABLE B6.2: MAIN EFFECT OF VOWEL; D3



MAIN EFFECT: VOWEL (wmanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	27639	7697.611	3.591	.034351
F2_CVCE	32635.	5200.665	6.275	.003544
F2_CVCE3	58934.	6427.270	9.169	.000373
F2_CVCVO	805650.	9283.746	86.781	.000000
F2_CVCVK	3797873.	3020.878	1257.208	0.000000

TABLE B6.3: CONSONANT BY VOWEL INTERACTION; D3



INTERACTION: 1 x 2 (wmanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,54	p-level
F2_CVCE1	27389.60	7697.611	3.558195	.035349
F2_CVCE	19613.07	5200.665	3.771261	.029302
F2_CVCE3	63567.15	6427.270	9.890225	.000219
F2_CVCVO	87611.45	9283.746	9.437079	.000306
F2_CVCVM	169.35	3020.878	.056060	.945538

TABLE B6.4 : Planned Comparisons ; D3

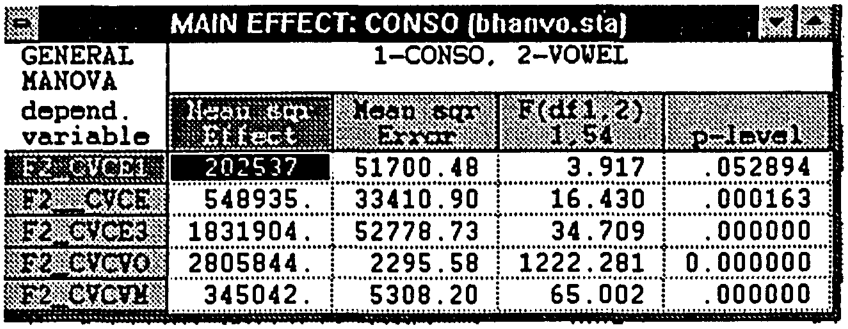
Comparison	*∂*1	*∂*2	*∂*3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=0.00094, p<.975714	F=2.50064, p<.119640	F=8.44654, p<.005294	F=19.29959, p<.000053*	F=85.74, p<.000000*
/∂bib/>/∂bub/	F=0.001, p<.951452	F=0.294, p<.589626	F=1.492, p<..227148	F=140.799, p<.000000*	F=1188.26, p<.000000*
/∂bab/</∂bub/	F=0.0037 p<.979763	F=4.5112 p<.03827	F=17.0399 p<.000128	F=55.8417 p<.000000*	F=635.6 p<.000000*
/∂did/>/∂dad/	F=12.29846 p<.000921	F=11.67547 p<.001211	F=9.91588 p<..00267*	F=23.12 p<.000013*	F=86.42 p<.000000*
/∂did/>/∂dud/	F=8.861 p<.00435*	F=11.152 p<.001527*	F=18.859 p<.000062*	F=45.76 p<.00000*	F=1161.85 p<.000000*
/∂dad/>/∂dud/	F=0.2810 p<.598205	F=0.0060 p<.938499	F=1.4251 p<237791	F=3.8274 p<..055602	F=614.27 p<.000000*

2. COARTICULATION IN DISYLLABLES – Coarticulation of consonant context.

HEARING TALKER H1

The results of the 2x3 multivariate analysis of variance indicated that the main effect of consonant (table B1.5) was significant at schwa midpoint, schwa offset, vowel onset and vowel midpoint. It was almost significant at the schwa onset (p<.052894).

TABLE B1.6: MAIN EFFECT OF CONSONANT; H1



MAIN EFFECT: CONSO (bhanvo.sta)

GENERAL MANOVA	1-CONSO, 2-VOWEL			
depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCE1	202537	51700.48	3.917	.052894
F2_CVCE	548935.	33410.90	16.430	.000163
F2_CVCE3	1831904.	52778.73	34.709	.000000
F2_CVCVO	2805844.	2295.58	1222.281	0.000000
F2_CVCVM	345042.	5308.20	65.002	.000000

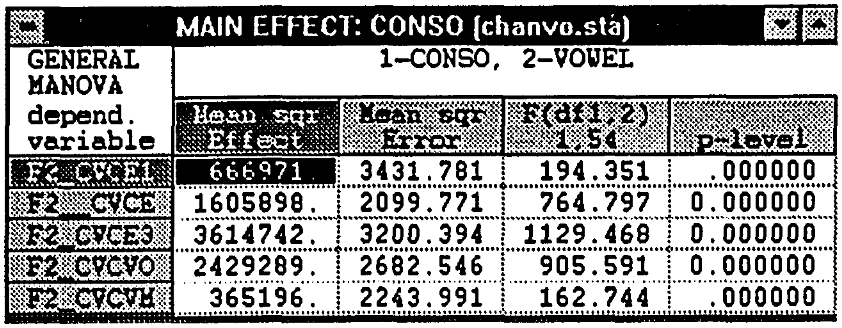
TABLE B1.6: Planned Comparisons; H1

Comparison	∂1	∂2	∂3	T onset	V mid
/∂dad/>/∂bab/	F=6.56, p<.0133	F=18.335, p<.00008*	F=36.0055, p<.00001*	F=495.427, p<.00001*	F=.3868, p<.5366
/∂did/>/∂bib/	F=1.13, p<.2933	F=8.59, p<.005*	F=12.3174, p<.0009*	F=11.757, p<.00118*	F=.0412, p<.5292
/∂dud/>/∂bub/	F=7.310, p<.0092	F=34.7, p<.000001*	F=40.590, p<.00001*	F=1261.07 p<.00001*	F=155.570 p<.00001*

As mentioned in section 1 of this Appendix., but also relevant here, the significant consonant x vowel interaction at vowel onset and vowel midpoint is due to greater coarticulatory impact of alveolar than bilabial context on high back vowel centers. This is inferred by the lower F2 means in /bub/ than /bab/ and the higher F2 means in /dud/ than /dad/ at vowel onset and vowel midpoint

HEARING TALKER H2

TABLE B2.5: MAIN EFFECT OF CONSONANT ; H2



MAIN EFFECT: CONSO (chanvo.stá)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCE1	666971.	3431.781	194.351	.000000
F2_CVCE	1605898.	2099.771	764.797	0.000000
F2_CVCE3	3614742.	3200.394	1129.468	0.000000
F2_CVCVO	2429289.	2682.546	905.591	0.000000
F2_CVCVM	365196.	2243.991	162.744	.000000

The results of a 2x3 multivariate analysis of variance, mentioned in section 1 of this Appendix, indicated that the main effect of consonant (table B2.5), was highly significant (p<.000001) across all measurement points of the disyllable. Thus, when data is averaged across vowel types, the alveolar disyllables have higher F2 means than the bilabial disyllables, across all measurement points.

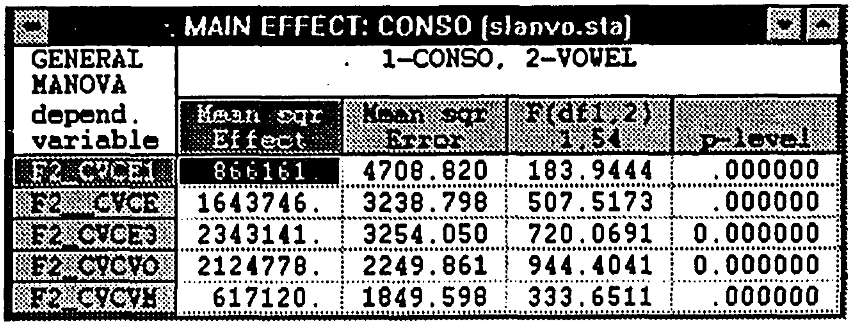
TABLE B2.6: Planned Comparisons; H2

Comparison	∂1	∂2	∂3	T onset	V mid
/∂dad/>/∂bab/	F=77.14, p<.00001*	F=249.35, p<.00001*	F=353.1, p<.00001*	F=496.08, p<.00001*	F=5.57, p<.0219
/∂did/>/∂bib/	F=62.91, p<.00001*	F=254.78, p<.00001*	F=372.66, p<.00001*	F=1.155, p<.287	F=.0771 p<.384
/∂dud/>/∂bub/	F=55.231, p<.00001*	F=260.73, p<.00001*	F=404.6, p<.00001*	F=827.98, p<.00001*	F=355.6 p<.00001*

The significant consonant x vowel interaction at vowel onset and midpoint, mentioned in section 1 but also relevant here, indicates carryover effects of preceding consonant at vowel onset, for disyllables with back vowel constrictions. Another consonant x vowel interaction is seen at [u] midpoint, where alveolar context yields significantly higher F2 values than bilabial context. The difference between the F2 means is 399.5 Hz.

HEARING TALKER H3

TABLE B3.5: MAIN EFFECT OF CONSONANT ; H3



MAIN EFFECT: CONSO (slanvo.sta)

GENERAL MANOVA	1-CONSO, 2-VOWEL			
depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCE1	866161.	4708.820	183.9444	.000000
F2_CVCE	1643746.	3238.798	507.5173	.000000
F2_CVCE3	2343141.	3254.050	720.0691	0.000000
F2_CVCVO	2124778.	2249.861	944.4041	0.000000
F2_CVCVM	617120.	1849.598	333.6511	.000000

The results of a 2x3 multivariate analysis of variance, mentioned in section 1 of this Appendix, indicated that the main effect of consonant (table B3.5), was highly significant ($p<.000001$) across all measurement points of the disyllable. Thus, when data is averaged across vowel types, the alveolar disyllables have higher F2 means than the bilabial disyllables, across all measurement points.

TABLE B3.6: Planned Comparisons; H3

Comparison	∂1	∂2	∂3	T onset	V mid
/∂dad/>/∂bab/	F=71.449, p<.00001*	F=165.2, p<.00001*	F=239.62, p<.00001*	F=389.78, p<.00001*	F=6.25, p<.0155
/∂did/>/∂bib/	F=40.67, p<.00001*	F=152.4, p<.00001*	F=191.79, p<.00001*	F=6.3135, p<.0150	F=.0411 p<.8401
/∂dud/>/∂bub/	F=75.018, p<.00001*	F=191.06, p<.00001*	F=294.1, p<.00001*	F=959.28, p<.00001*	F=837.19 p<.00001*

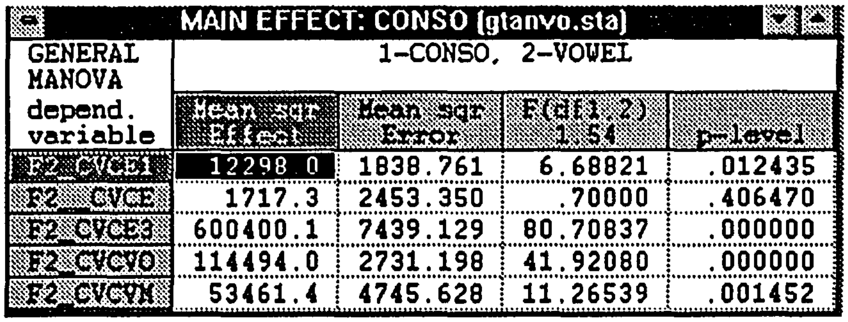
The significant consonant x vowel interaction at vowel onset and midpoint, mentioned in section 1 but also relevant here, indicates carryover effects of preceding consonant at vowel onset, for disyllables with *back* vowel constrictions. Another consonant x vowel interaction is seen at [u] midpoint, where alveolar context yields significantly higher F2 values than bilabial context.

DEAF TALKER D1

A 2x3 multivariate factorial analysis revealed that the Wilks' lamda for the consonant main effect and the consonant x vowel interaction was highly significant (see Table B4.4). Univariate results indicated that the main effect of consonant, collapsed across vowel type, was highly significant at schwa onset, schwa offset, vowel onset and vowel midpoint (Table B4.5).

The consonant x vowel interaction (see Table B4.4 in section 1) was significant at the vowel onset and at the vowel midpoint. The interaction at vowel midpoint indicates that coarticulatory effects of the consonant context were present for disyllables containing the vowel [u], but not present otherwise. The interaction at vowel onset indicated that carryover effects of consonant context are present for disyllables containing the vowel [a] but not otherwise.

TABLE B4.5: MAIN EFFECT OF CONSONANT; D1



MAIN EFFECT: CONSO (gtanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCE1	12298.0	1838.761	6.68821	.012435
F2__CVCE	1717.3	2453.350	.70000	.406470
F2_CVCE3	600400.1	7439.129	80.70837	.000000
F2_CVCVO	114494.0	2731.198	41.92080	.000000
F2_CVCVM	53461.4	4745.628	11.26539	.001452

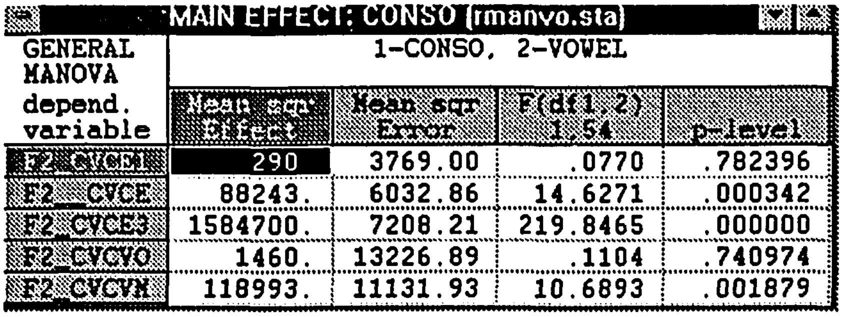
TABLE B4.6: Planned Comparisons ; D1

Comparison	∂1	∂2	∂3	T onset	V mid
/∂dad/</∂bab/	F=4.157, p<.046	F=.0059, p<.939	F=28.55, p<.00001*	F=90.794, p<.00001*	F=1.894, p<.17442
/∂did/>/∂bib/	F=.393, p<.534	F=.0138, p<.907	F=28.47, p<.000002*	F=.633, p<.4296	F=3.0157, p<.0882
/∂dud/>/∂bub/	F=3.2931, p<.075	F=2.70, p<.106	F=23.83, p<.00001*	F=.792, p<.3774	F=29.74, p<.00001*

DEAF TALKER D2

A 2x3 multivariate analysis indicated a significant Wilks' lamda for the main effect of consonant as well as the consonant by vowel interaction (see Tables B5.5. B5.4, respectively). Univariate results indicated that the consonant main effect is significant for the schwa midpoint, schwa offset and vowel midpoint. The consonant by vowel interaction was significant at the vowel onset and the vowel midpoint. The interaction at vowel onset indicates that different carryover effects as a function of vowel type. Recall that in disyllables containing high vowels, bilabial context has greater influences than alveolar context. The interaction at vowel midpoint indicate that symmetrical consonant context shows coarticulatory effects at the midpoint of the stressed syllable for [u] centers only.

TABLE B5.5: MAIN EFFECT OF CONSONANT; D2



MAIN EFFECT: CONSO (rmanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCEM	290	3769.00	.0770	.782396
F2_CVCE	88243.	6032.86	14.6271	.000342
F2_CVCE3	1584700.	7208.21	219.8465	.000000
F2_CVCVO	1460.	13226.89	.1104	.740974
F2_CVCVM	118993.	11131.93	10.6893	.001879

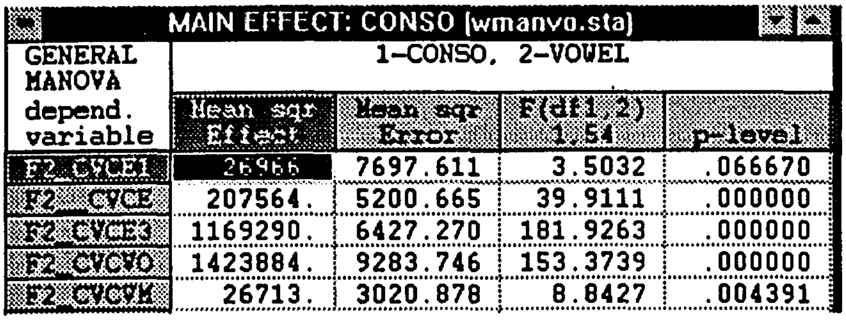
TABLE B5.6: Planned Comparisons; D2

Comparison	ə1	ə2	ə3	T onset	V mid
/ədad/>/əbab/	F=.911, p<.3442	F=2.064, p<.1566	F=98.90, p<.00001*	F=38.083, p<.00001*	F=.0317, p<.859
/ədid/>/əbib/	F=.01445, p<.905	F=9.992, p<.00258*	F=56.54, p<.00001*	F=.9.665, p<.0030*	F=.525, p<.4717
/ədud/>/əbub/	F=.1248, p<.7253	F=4.108, p<.048	F=67.523, p<.00001*	F=13.23, p<.00062	F=22.658, p<.00002*

DEAF TALKER D3

A 2x3 multivariate analysis indicated a significant Wilks' lamda for the main effect of consonant as well as the consonant by vowel interaction (see Tables B6.5, B6.6, respectively). Univariate results indicated that the consonant main effect is significant at the schwa midpoint, schwa offset, vowel onset and vowel midpoint. The consonant by vowel interaction was significant at schwa onset, schwa midpoint, schwa offset and vowel onset. The interaction at schwa onset indicates that significant anticipation of consonant context occurs in disyllables with front high vowels ([i]) only. The interaction at the schwa midpoint indicates that significant anticipation of consonant context occurs in disyllables with high vowels only.

TABLE B6.5: MAIN EFFECT OF CONSONANT; D3



MAIN EFFECT: CONSO (wmanvo.sta)

GENERAL MANOVA depend. variable	1-CONSO, 2-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 1,54	p-level
F2_CVCE1	26966	7697.611	3.5032	.066670
F2_CVCE	207564.	5200.665	39.9111	.000000
F2_CVCE3	1169290.	6427.270	181.9263	.000000
F2_CVCVO	1423884.	9283.746	153.3739	.000000
F2_CVCVM	26713.	3020.878	8.8427	.004391

TABLE B6.6: Planned Comparisons; D3

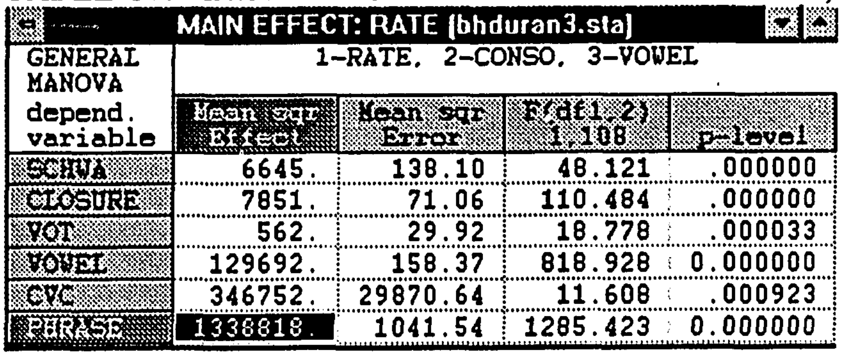
Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂dad/>/∂bab/	F=.055, p<.8155	F=13.82, p<.0005*	F=89.88, p<.00001*	F=26.76, p<.00001*	F=2.44, p<.1241
/∂did/>/∂bib/	F=10.51 p<.0020*	F=30.84, p<.00001*	F=94.536, p<.00001*	F=31.229, p<.00001*	F=2.5564, p<.11569
/∂dud/>/∂bub/	F=.055, p<.815	F=2.79, p<.10046	F=17.294, p<.00012*	F=114.26, p<.00001*	F=3.96, p<.0517*

APPENDIX C

RATE EFFECTS ON DURATION OF UTTERANCE SEGMENTS

Tables C1-C6 present the univariate results of 2x2x3 MANOVAS performed on durations of various parts of the phrase "a CVC again", for each of the six talkers.

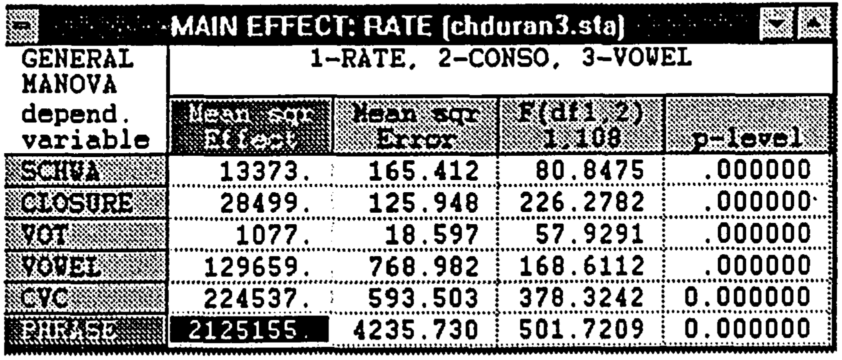
TABLE C1: MAIN EFFECT OF RATE ON DURATIONS; H1



MAIN EFFECT: RATE (bhduran3.sta)

GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
SCHWA	6645.	138.10	48.121	.000000
CLOSURE	7851.	71.06	110.484	.000000
VOT	562.	29.92	18.778	.000033
VOWEL	129692.	158.37	818.928	0.000000
CVC	346752.	29870.64	11.608	.000923
PHRASE	1338818.	1041.54	1285.423	0.000000

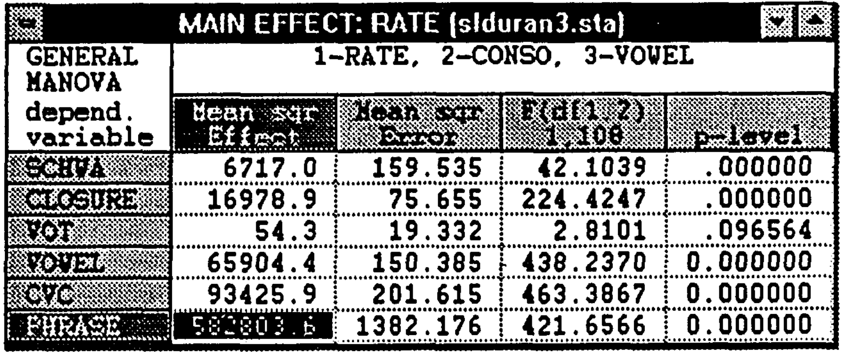
TABLE C2: MAIN EFFECT OF RATE ON DURATIONS; H2



MAIN EFFECT: RATE (chduran3.sta)

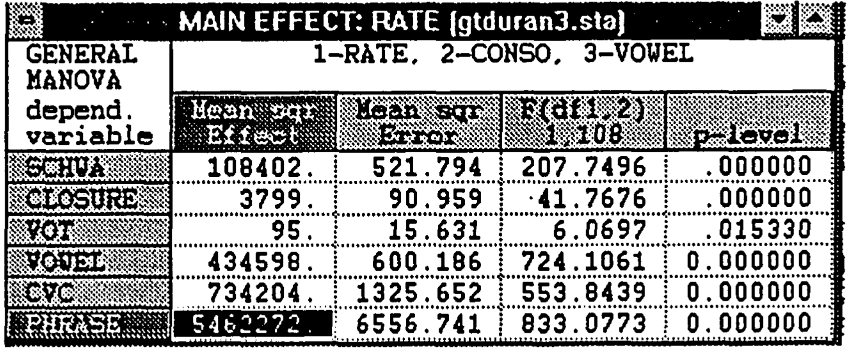
GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
SCHWA	13373.	165.412	80.8475	.000000
CLOSURE	28499.	125.948	226.2782	.000000
VOT	1077.	18.597	57.9291	.000000
VOWEL	129659.	768.982	168.6112	.000000
CVC	224537.	593.503	378.3242	0.000000
PHRASE	2125155.	4235.730	501.7209	0.000000

TABLE C3: MAIN EFFECT OF RATE ON DURATIONS; H3



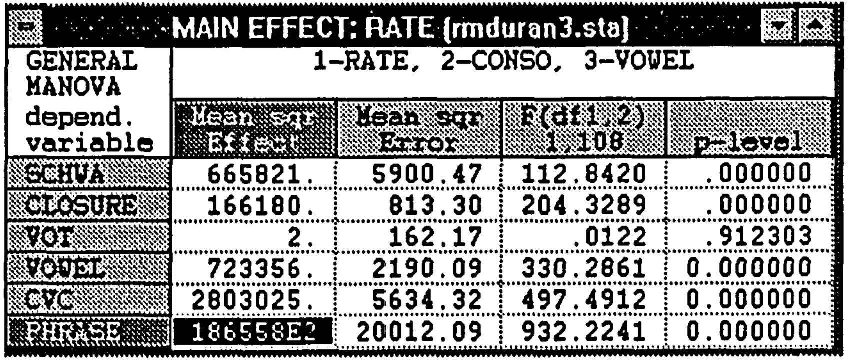
GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
SCHWA	6717.0	159.535	42.1039	.000000
CLOSURE	16978.9	75.655	224.4247	.000000
VOT	54.3	19.332	2.8101	.096564
VOWEL	65904.4	150.385	438.2370	0.000000
CVC	93425.9	201.615	463.3867	0.000000
PHRASE	582803.6	1382.176	421.6566	0.000000

TABLE C4: MAIN EFFECT OF RATE ON DURATIONS; D1



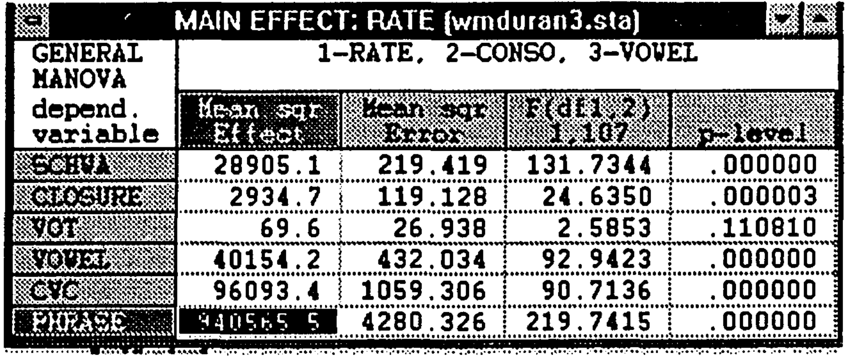
GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
SCHWA	108402.	521.794	207.7496	.000000
CLOSURE	3799.	90.959	41.7676	.000000
VOT	95.	15.631	6.0697	.015330
VOWEL	434598.	600.186	724.1061	0.000000
CVC	734204.	1325.652	553.8439	0.000000
PHRASE	5462272.	6556.741	833.0773	0.000000

TABLE C5: MAIN EFFECT OF RATE ON DURATIONS; D2



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
SCHWA	665821.	5900.47	112.8420	.000000
CLOSURE	166180.	813.30	204.3289	.000000
VOT	2.	162.17	.0122	.912303
VOWEL	723356.	2190.09	330.2861	0.000000
CVC	2803025.	5634.32	497.4912	0.000000
PHRASE	186558E2	20012.09	932.2241	0.000000

TABLE C6: MAIN EFFECT OF RATE ON DURATIONS; D3



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,107	p-level
SCHWA	28905.1	219.419	131.7344	.000000
CLOSURE	2934.7	119.128	24.6350	.000003
VOT	69.6	26.938	2.5853	.110810
VOWEL	40154.2	432.034	92.9423	.000000
CVC	96093.4	1059.306	90.7136	.000000
PHRASE	940565.5	4280.326	219.7415	.000000

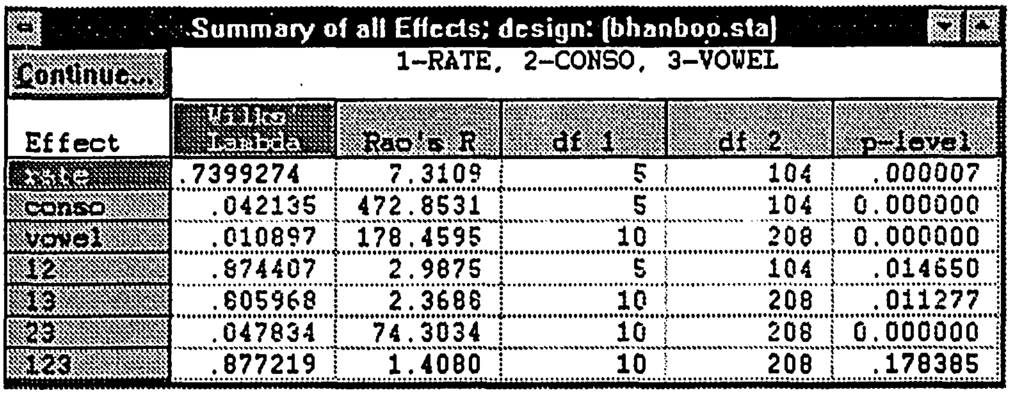
APPENDIX D

EFFECTS OF RATE ON COARTICULATION OF DISYLLABLES

1. COARTICULATION OF VOWEL CONTEXT

A 2x2x3 three-way MANOVA was computed for talker H1 in order to assess the effects of rate on coarticulation of consonant and vowel constrictions in disyllables "əCVC". The average F2 values at schwa onset, schwa midpoint, schwa offset, vowel onset and vowel midpoint were examined as a function of "RATE", "CONSONANT TYPE" AND "VOWEL TYPE". The analysis below will place emphasis on the univariate results of the main effect of rate and its interactions. Table D1 and D1.2-D1.4 present the analysis for N-H talker H1

TABLE D1: SUMMARY TABLE; H1

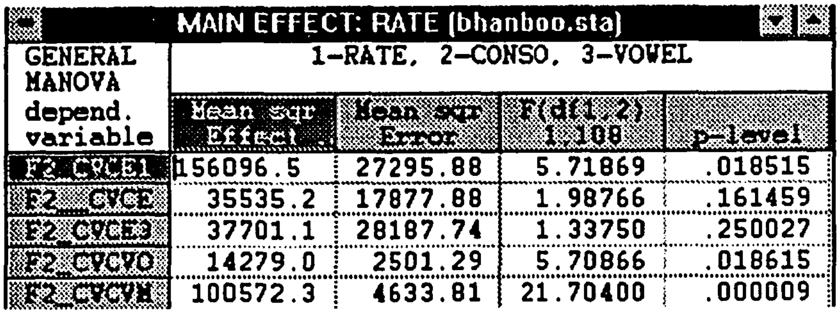


Summary of all Effects; design: (bhanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

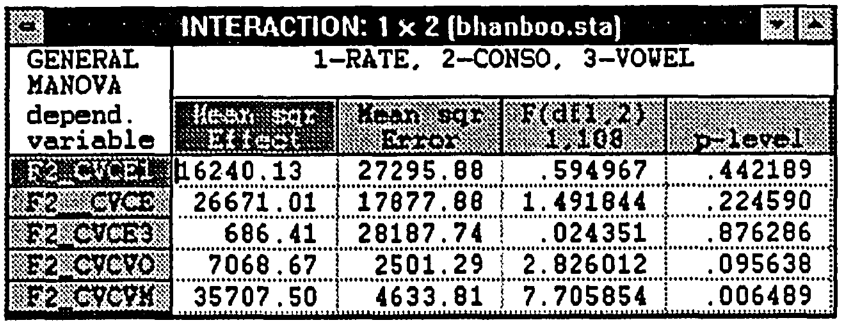
Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.7399274	7.3109	5	104	.000007
conso	.042135	472.8531	5	104	0.000000
vowel	.010897	178.4595	10	208	0.000000
12	.874407	2.9875	5	104	.014650
13	.605968	2.3686	10	208	.011277
23	.047834	74.3034	10	208	0.000000
123	.877219	1.4080	10	208	.178385

TABLE D1.2 : MAIN EFFECT OF RATE; H1



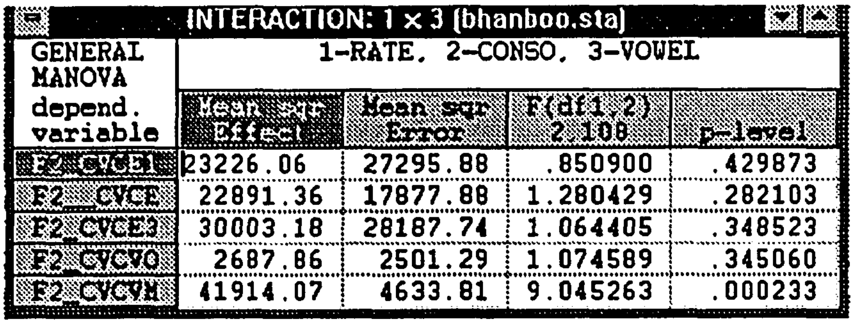
GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
F2_CVCE1	156096.5	27295.88	5.71869	.018515
F2__CVCE	35535.2	17877.88	1.98766	.161459
F2_CVCE3	37701.1	28187.74	1.33750	.250027
F2_CVCVO	14279.0	2501.29	5.70866	.018615
F2_CVCVM	100572.3	4633.81	21.70400	.000009

TABLE D1.3: RATE X CONSONANT INTERACTION; H1



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
F2_CVCE1	16240.13	27295.88	.594967	.442189
F2__CVCE	26671.01	17877.88	1.491844	.224590
F2_CVCE3	686.41	28187.74	.024351	.876286
F2_CVCVO	7068.67	2501.29	2.826012	.095638
F2_CVCVM	35707.50	4633.81	7.705854	.006489

TABLE D1.4: RATE X VOWEL INTERACTION; H1



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,108	p-level
F2_CVCE1	23226.06	27295.88	.850900	.429873
F2__CVCE	22891.36	17877.88	1.280429	.282103
F2_CVCE3	30003.18	28187.74	1.064405	.348523
F2_CVCVO	2687.86	2501.29	1.074589	.345060
F2_CVCVM	41914.07	4633.81	9.045263	.000233

As seen in Table D1, Wilks' lamda is significant for the main effect of rate and its interactions with consonant and vowel type. The univariate analysis of the midpoint (F=21.709, df=1, p<.000009) with respect to increases in F2 at fast rates. Note that the significant F ratio at vowel onset reflects decreased F2 values with increased rate (see Fig. 54).

TABLE D1.5 : Planned Comparisons ; H1 ; at Fast rate

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=14.193, p<.00027*	F= 25.720, p<.00001*	F=23.454, p<.00001*	F=1264.88, p<.00001*	F=951.162, p<.00001*
/∂bib/>/∂bub/	F=11.315, p<.00107*	F= 16.843, p<.00008*	F= 31.972, p<.00001*	F= 1837.8, p<.00001*	F=1578.09, p<.00001*
/∂bab/>/∂bub/	F=.16293, p<.6873	F=.93589, p<.33554	F=.6584, p<.4189	F=53.35, p<.00001*	F= 72.21, p<.00001*
/∂did/>/∂dad/	F=1.1671 , p<.28244	F= 1.7007, p<.19503	F= 7.197, p<.0085	F=369.6 , p<.00001*	F= 960.144, p<.00001*
/∂did/>/∂dud/	F=4.3824 , p<.0387	F=2.7767 , p<.0986	F=1.712, p<.1935	F=123.78 , p<.00001*	F= 505.44, p<.00001*
/∂dud/>/∂dad/	F=1.02632 , p<.31333	F=.13122 , p<.717888	F=1.889, p<.172249	F= 65.59, p<.00001*	F=72.321 , p<.00001*

TABLE D1.6: Planned comparisons of contrastive disyllables at normal vs. Fast rate; H1

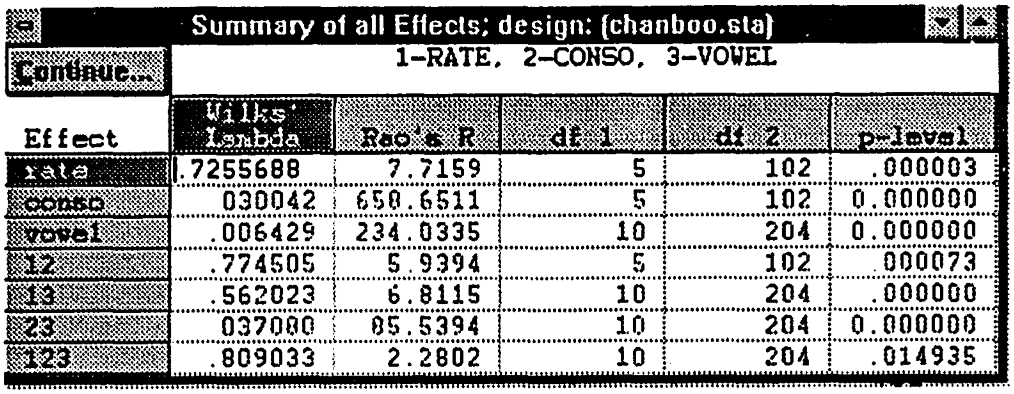
Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=1.476, p<.22715	F=.621012, p<.43243	F=.56048, p<.455723	F=.139638, p<.709388	F=2.803, p<.0971
/∂bib/>/∂bub/	F=.90517, p<.343564	F=.196236, p<.658679	F=1.62348, p<.205394	F=.171034, p<.68003	F=1.6153, p<.2065
/∂bab/>/∂bub/	F=.07636, p<.78284	F=.12326, p<..72622	F=.25823, p<.61239	F=.00117, p<.97274	F=.1768, p<.6750
/∂did/>/∂dad/	F=.00987, p<.92103	F=.20444, p<.6521	F=3.0446, p<.0839	F=.34802, p<..5565	F=3.7353, p<.0559
/∂did/>/∂dud/	F=.572, p<.4512	F=.06103, p<.80535	F=.48951, p<.485678	F=1.8312, p<.178867	F=19.87, p<.00002*
/∂dud/>/∂dad/	F=.44353, p<.50687	F=.04324, p<.83568	F=1.12285, p<.29172	F=3.8807, p<..051453	F=6.555, p<.0119

HEARING TALKER H2

Tables D2, D2.2.-D2.4 present the results of a 2x2x3 multivariate factorial analysis with respect to rate effects on F2 values along the disyllable. The Wilks' lamda (see Table D2) was highly significant for the main effect of rate, the main effect of vowel, the rate x vowel interaction and the rate x vowel x consonant interaction.

Univariate analysis revealed significant F ratios (see Table D2.2) on main effect of rate for the schwa onset, schwa midpoint, schwa offset and vowel midpoint. Also, univariate analysis indicated significant F ratios on the rate x vowel interaction at the schwa midpoint, schwa offset, vowel onset and vowel midpoint (see Table D2.3). In addition, a rate x vowel x consonant interaction (see Table D2.4.) was significant at the schwa parts (schwa onset, schwa midpoint and schwa offset).

TABLE D2: SUMMARY TABLE; H2

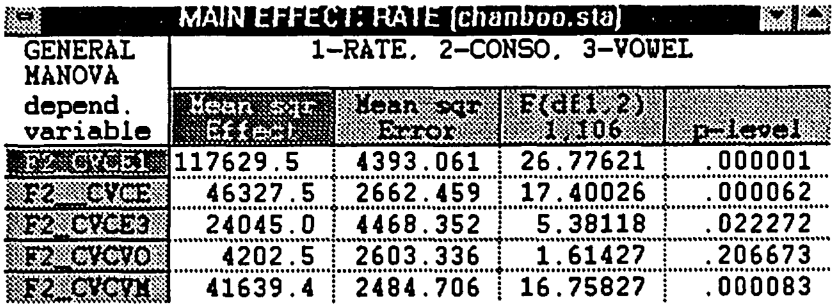


Summary of all Effects; design: (chanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.7255688	7.7159	5	102	.000003
conso	030042	650.6511	5	102	0.000000
vowel	.006429	234.0335	10	204	0.000000
12	.774505	5.9394	5	102	.000073
13	.562023	6.8115	10	204	.000000
23	037000	85.5394	10	204	0.000000
123	.809033	2.2802	10	204	.014935

TABLE D2.2: MAIN EFFECT OF RATE; H2

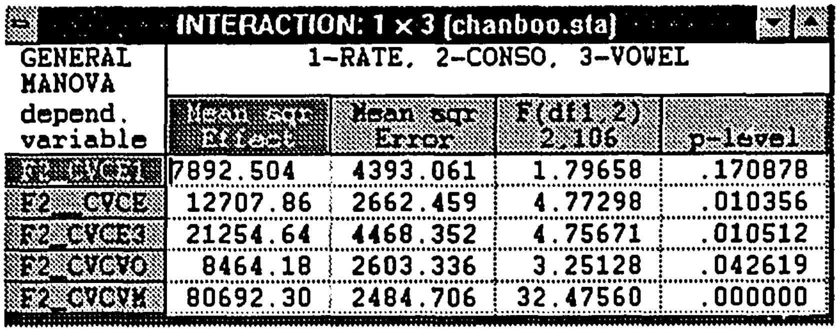


MAIN EFFECT: RATE (chanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,106	p-level
[illegible]	117629.5	4393.061	26.77621	.000001
F2_CVCE	46327.5	2662.459	17.40026	.000062
F2_CVCE3	24045.0	4468.352	5.38118	.022272
F2_CVCVO	4202.5	2603.336	1.61427	.206673
F2_CVCVM	41639.4	2484.706	16.75827	.000083

TABLE D2.3: RATE X VOWEL INTERACTION; H2

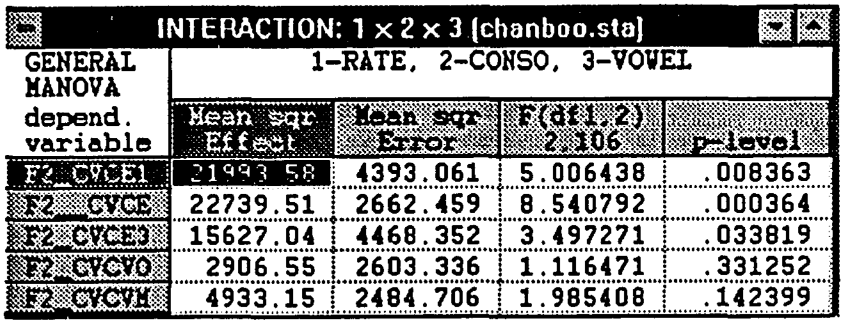


INTERACTION: 1 x 3 (chanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,106	p-level
[illegible]	7892.504	4393.061	1.79658	.170878
F2_CVCE	12707.86	2662.459	4.77298	.010356
F2_CVCE3	21254.64	4468.352	4.75671	.010512
F2_CVCVO	8464.18	2603.336	3.25128	.042619
F2_CVCVM	80692.30	2484.706	32.47560	.000000

TABLE D2.4: RATE X CONSONANT X VOWEL INTERACTION; H2



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,106	p-level
F2_CVCE1	21993.58	4393.061	5.006438	.008363
F2_CVCE	22739.51	2662.459	8.540792	.000364
F2_CVCE3	15627.04	4468.352	3.497271	.033819
F2_CVCVO	2906.55	2603.336	1.116471	.331252
F2_CVCVM	4933.15	2484.706	1.985408	.142399

The univariate results of rate x vowel interaction and rate x consonant x vowel interaction indicate that as mentioned above, that the schwa parts of disyllables with [i] centers show greater increases with rate in bilabial environments whereas the schwa parts of disyllables with [a] and [u] centers show greater increases with rate in alveolar environments. Significant F2 increases with increased speaking rate at vowel midpoint are noted for disyllables, alveolar and bilabial, containing [u] vowel centers (a rate x vowel interaction).

TABLE D2.5: Planned comparisons; Contrastive disyllables at fast rate; H2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=82.358, p<.000000*	F=144.511, p<.000000*	F=61.376, p<.000000*	F=1763.77, p<.000000*	F=1887.1 p<.00001*
/∂bib/>/∂bub/	F=43.057, p<.000000*	F=90.728, p<.000000*	F=55.646, p<.000000*	F=1307.534, p<.000000*	F=1962.3, p<.00001*
/∂bab/>/∂bub/	F=6.3171, p<.013463	F=6.2306, p<..0141	F=.14036, p<.708667	F=34.076, p<.000000*	F=.734, p<.395
/∂did/>/∂dad/	F=5.158, p<.0252	F=15.121, p<.000176*	F=13.15, p<.000444*	F=336.174, p<.000000*	F=1288.2, p<.00001*
/∂did/>/∂dud/	F=3.922, p<.05026	F=11.661, p<.00091*	F=4.069, p<.046212	F=99.754, p<.000000*	F=604.53, p<.00001*
/∂dud/>/∂dad/	F=.1632, p<.68706	F=.4476, p<.505	F=12.9734, p<.08756	F=79.5441, p<.000000*	F=161.58, p<.00001*

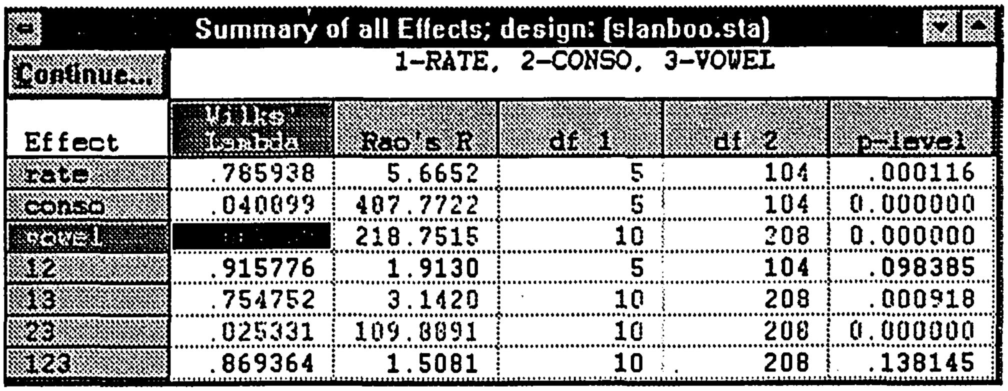
TABLE D2.6: Planned comparisons; contrastive disyllables at normal vs. fast rate; H2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=11.378, p<.00104*	F=25.595, p<.000002*	F=12.995, p<.000478*	F=.00004, p<.9951	F=1.618, p<.2062
/∂bib/>/∂bub/	F=4.025, p<.04738	F=10.9117, p<.001304*	F=11.618, p<.000925*	F=5.7827, p<.0179	F=22.73, p<.000006*
/∂bab/>/∂bub/	F=1.8685, p<.17454	F=3.083, p<..082	F=.03854, p<.8447	F=5.753, p<.0182	F=12.22, p<.0007*
/∂did/>/∂dad/	F=.615, p<..4345	F=.3759, p<.5411	F=21.433, p<.644341	F=.5098, p<.47679	F=15.624, p<.00014*
/∂did/>/∂dud/	F=2.3896, p<.125	F=.8116, p<.36968	F=.00202, p<.964238	F=1.0585, p<.3059	F=43.87, p<.00001*
/∂dud/>/∂dad/	F=.5114, p<.4761	F=.0681, p<.7947	F=.175865, p<..6758	F=0.807, p<.77689	F=6.12, p<.015

DEAF TALKER D1

A 2x2x3 MANOVA revealed a significant Wilks' lamda for the main effects of rate and vowel. The rate x vowel effect was also significant (see Table D3.3).

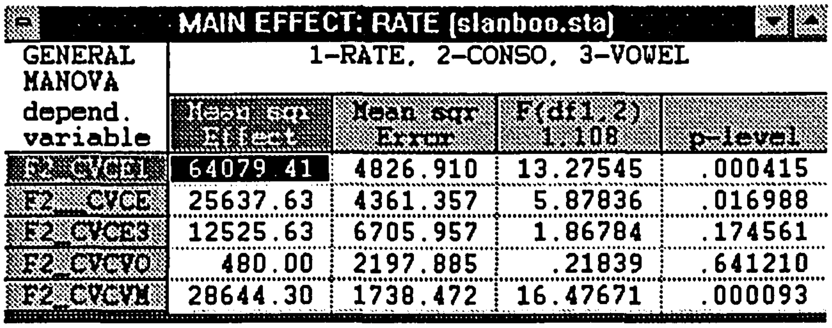
TABLE D3: SUMMARY TABLE; H3



1-RATE, 2-CONSO, 3-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.785938	5.6652	5	104	.000116
conso	.040099	407.7722	5	104	0.000000
vowel	[illegible]	218.7515	10	208	0.000000
12	.915776	1.9130	5	104	.098385
13	.754752	3.1420	10	208	.000918
23	.025331	109.8091	10	208	0.000000
123	.869364	1.5081	10	208	.138145

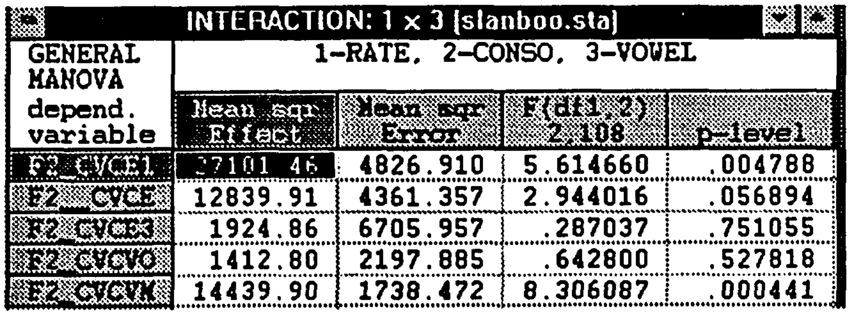
TABLE D3.2: MAIN EFFECT OF RATE; H3



1-RATE, 2-CONSO, 3-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
F2_CVCE1	64079.41	4826.910	13.27545	.000415
F2_CVCE	25637.63	4361.357	5.87836	.016988
F2_CVCE3	12525.63	6705.957	1.86784	.174561
F2_CVCVO	480.00	2197.885	.21839	.641210
F2_CVCVM	28644.30	1738.472	16.47671	.000093

TABLE D3.3: RATE X VOWEL INTERACTION; H3



INTERACTION: 1 x 3 [slanboo.sta]

GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,108	p-level
F2_CVCE1	27101.46	4826.910	5.614660	.004788
F2_CVCE	12839.91	4361.357	2.944016	.056894
F2_CVCE3	1924.86	6705.957	.287037	.751055
F2_CVCVO	1412.80	2197.885	.642800	.527818
F2_CVCVK	14439.90	1738.472	8.306087	.000441

Univariate results of the main effect of rate (see Table D3.2) indicate significant F2 changes with increased rate for schwa onset, schwa midpoint, and vowel midpoint. The rate x vowel interaction was significant at those same measurement points (see Table D3.3).

TABLE D3.5 : Planned Comparisons ; H3 ; at Fast rate

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=39.348, p<.000000*	F=42.306, p<.000000*	F=18.637, p<.000035*	F=1207.6 p<.00001*	F=1996.1, p<.00001*
/∂bib/>/∂bub/	F=41.352, p<.000000*	F=29.532, p<.000000*	F=14.056, p<.000287*	F=1246.7, p<.00001*	F=2592.9, p<.00001*
/∂bab/>/∂bub/	F=.02487, p<87498	F=1.14478, p<..287030	F=.32258, p<.571241	F=.312, p<.578	F=38.97, p<.00001*
/∂did/>/∂dad/	F=.16.005, p<.000116*	F=18.172, p<.000043*	F=12.446, p<..000616*	F=290.4, p<.00001*	F=1775.5, p<.00001*
/∂did/>/∂dud/	F=7.502, p<.007212	F=1.067, p<.304052	F=2.6396, p<.107143	F=54.65, p<.00001*	F=706.71, p<.00001*
/∂dud/>/∂dad/	F=1.5917, p<.209795	F=10.4339, p<.00164*	F=3.6222, p<.059675	F=93.10, p<.00001*	F=241.88, p<.00001*

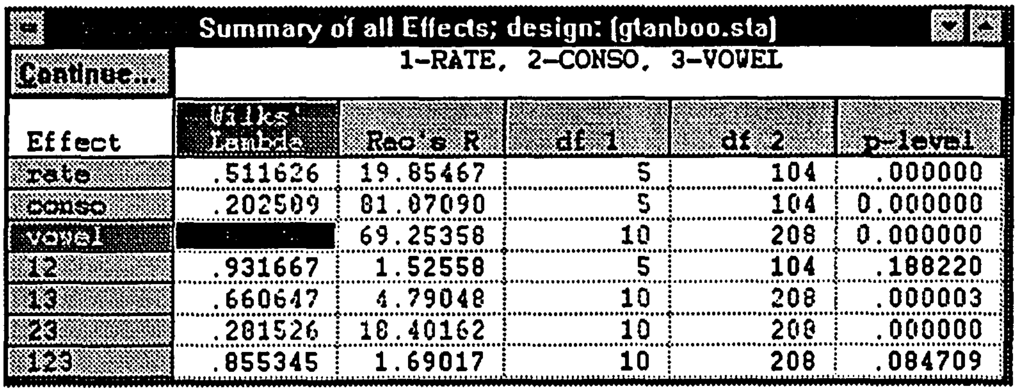
TABLE D3.6: Planned comparisons; Contrastive disyllables at normal vs. fast rate; H3

Comparison	**∂1**	**∂2**	**∂3**	**T onset**	**V mid**
/∂bib/>/∂bab/	F= 4.694, p<.03247	F= 5.3823, p<.0222	F=.136, p<.7130	F=.415, p<.52083	F= 4.7051, p<.03227
/∂bib/>/∂bub/	F= 6.358, p<.01314	F=5.022 , p<.0271	F= .136, p<.71301	F= .892, p<.3471	F= 20.881, p<.00001*
/∂bab/>/∂bub/	F=.12604, p<.72326	F=.00624 , p<..93717	F= .000000, p<1.00000	F=.090, p<.7646	F=5.762 , p<.0181
/∂did/>/∂dad/	F= 4.038, p<.047	F= 1.089, p<..29887	F=.37699, p<.54051	F= .7052, p<.40289	F= 5.246, p<.024
/∂did/>/∂dud/	F=2.2698 , p<.13484	F=.00083, p<.97713	F=.242415, p<.62347	F= .1048, p<.7467	F=.67716, p<.4124
/∂dud/>/∂dad/	F=2529, p<.61602	F=1.0305, p<.31231	F=014797, p<.90341	F=.266, p<.6069	F= 2.154, p<.145

DEAF TALKER D1

A 2x2x3 multivariate analysis for D1 shows significant Wilks' lamda for the main effect of rate and the rate x vowel interaction (Table D4).

TABLE D4: SUMMARY TABLE; D1

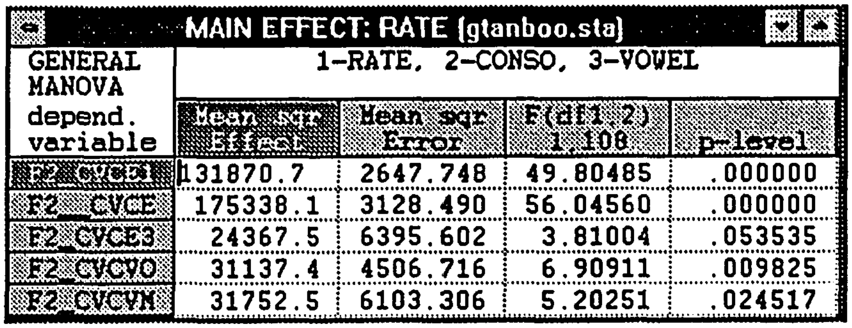


Summary of all Effects; design: (gtanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.511626	19.85467	5	104	.000000
conso	.202509	81.07090	5	104	0.000000
vowel		69.25358	10	208	0.000000
12	.931667	1.52558	5	104	.188220
13	.660647	4.79048	10	208	.000003
23	.281526	18.40162	10	208	.000000
123	.855345	1.69017	10	208	.084709

TABLE D4.2: MAIN EFFECT OF RATE; D1

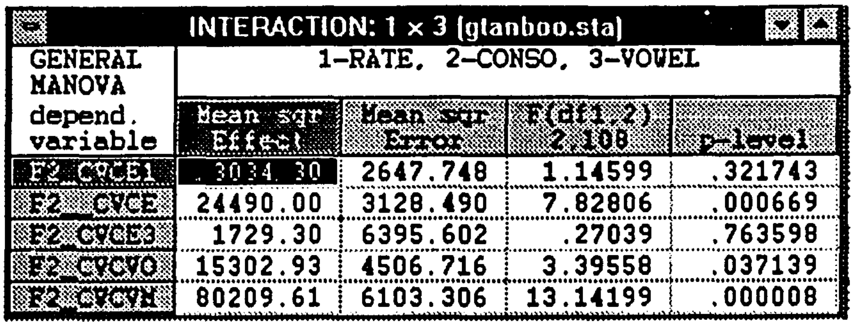


MAIN EFFECT: RATE (gtanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
[illegible]	131870.7	2647.748	49.80485	.000000
F2_CVCE	175338.1	3128.490	56.04560	.000000
F2_CVCE3	24367.5	6395.602	3.81004	.053535
F2_CVCVO	31137.4	4506.716	6.90911	.009825
F2_CVCVM	31752.5	6103.306	5.20251	.024517

TABLE D4.3: RATE X VOWEL INTERACTION; D1



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,108	p-level
F2_CVCE1	3034.30	2647.748	1.14599	.321743
F2__CVCE	24490.00	3128.490	7.82806	.000669
F2_CVCE3	1729.30	6395.602	.27039	.763598
F2_CVCVO	15302.93	4506.716	3.39558	.037139
F2_CVCVM	80209.61	6103.306	13.14199	.000008

Univariate results indicated significant F ratios for the main effect of rate (see Table D4.2) at schwa onset, schwa midpoint, vowel onset and vowel midpoint and nearly significant F ratios at schwa offset (p<. 0535). The rate x vowel interaction (see Table D4.3) was significant at schwa midpoint, vowel onset and vowel midpoint. The interaction effect pertains to greater F2 increases with faster rates at schwa midpoint of disyllables with front consonant-vowel targets (CiC). Also, the vowel midpoints of disyllables containing high vowels in /əbib/ and /ədud/ show F2 decreases with increased rate (a phenomenon of neutralization).

TABLE D4.5: Planned comparisons; Contrastive disyllables at fast rate;
D1

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=15.672 , p<.000135*	F=43.038 , p<.000000*	F= 15.105, p<.000176*	F= 230.392, p<.00001*	F= 192.86, p<.00001*
/∂bib/>/∂bub/	F=9.1477, p<.003112*	F=23.7099 p<.000004*	F=6.9079, p<.00983	F= 21.313, p<.000011*	F= 20.555, p<.00001*
/∂bab/>/∂bub/	F=.8729, p<.352235	F=2.8597, p<.09371	F=1.5831 , p<.211025	F=111.558 , p<.00001*	F= 87.49, p<.00001*
/∂did/>/∂dad/	F=20.4249, p<.000016*	F=44.1466, p<.000000*	F=8.9006, p<.003525*	F=28.473, p<.000001*	F= 139.6, p<.00001*
/∂did/>/∂dud/	F= 13.198, p<.000431*	F= 32.408, p<.000000*	F=.1342 , p<.71487	F= 5.1603, p<.0251	F= 140.28, p<.00001*
/∂dud/>/∂dad/	F= .78587, p<.37732	F=90529, p<.34349	F= 6.84921, p<.01014	F= 9.3904, p<.002755*	F=.00082, p<.97722

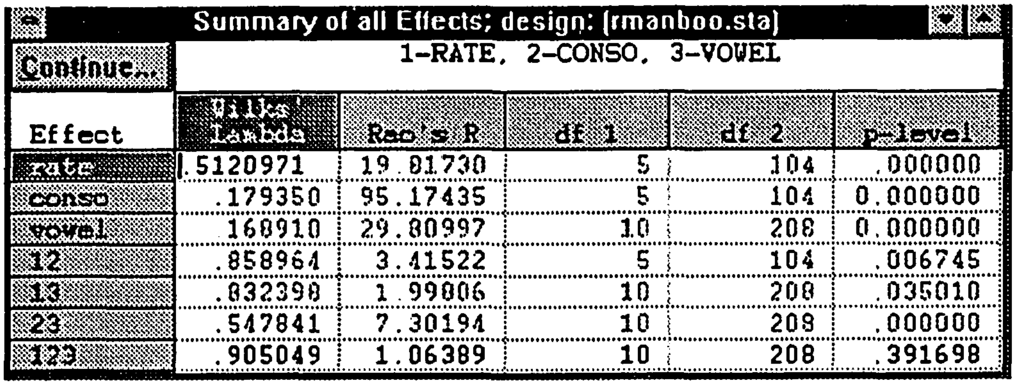
TABLE D4.6: Planned comparisons; Contrastive disyllables at normal vs. fast rate; D1

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=.94284, p<.33372	F= 2.9153, p<.09062	F= .00285, p<.95753	F= .1817, p<.6707	F= 7.789, p<.0062
/∂bib/>/∂bub/	F= 1.38061, p<.24428	F=9.18322 , p<.00306*	F=1.5123, p<.22146	F=3.88625, p<.051241	F=.22429, p<.6367
/∂bab/>/∂bub/	F=.0399, p<.84206	F= 1.75024, p<.188641	F=1.38386, p<.24203	F= 2.3872, p<.12526	F=5.370, p<.0224
/∂did/>/∂dad/	F=.285866, p<.59398	F= 3.0322, p<.08447	F= .33558, p<.563599	F=2.9805, p<.087133	F=5.361, p<.02248
/∂did/>/∂dud/	F=.81059, p<.36995	F= 6.3013, p<.013547	F=.5122 , p<.4757	F= .133273, p<.715776	F=5.655, p<.0192
/∂dud/>/∂dad/	F=.13371 , p<.715533	F= 59121, p<.44363	F=01861 , p<.891743	F=4.3743, p<.03883	F=22.03 , p<.00001*

DEAF TALKER D2

Tables D5, D5.2-D5.4 present the results of a 2x2x3 MANOVA for D2.

TABLE D5: SUMMARY; D2

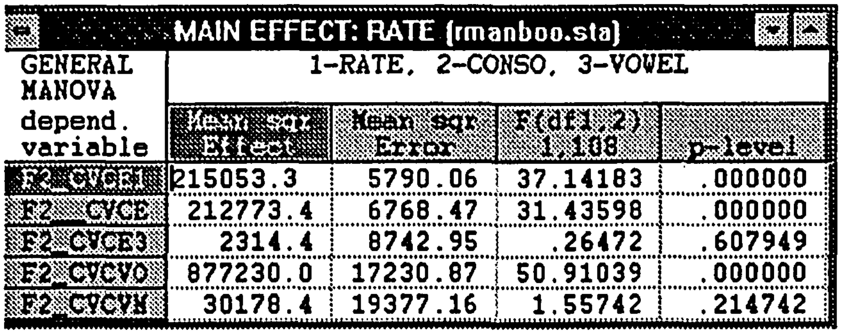


Summary of all Effects; design: (rmanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.5120971	19.81730	5	104	.000000
conso	.179350	95.17435	5	104	0.000000
vowel	168910	29.80997	10	208	0.000000
12	.858964	3.41522	5	104	.006745
13	.832398	1.99806	10	208	.035010
23	.547841	7.30194	10	209	.000000
123	.905049	1.06389	10	208	.391698

TABLE D5.2: MAIN EFFECT OF RATE; D2

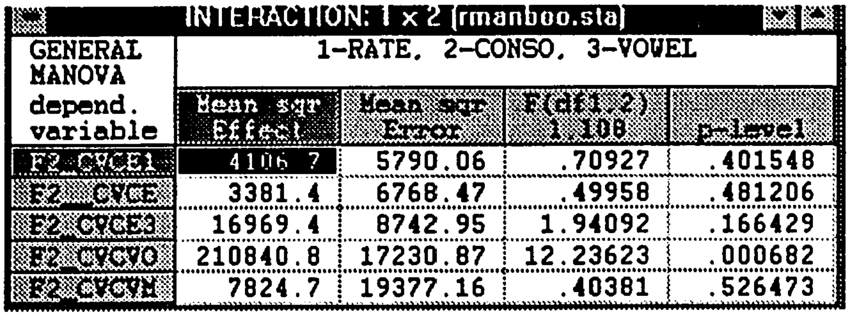


MAIN EFFECT: RATE (rmanboo.sta)

1-RATE, 2-CONSO, 3-VOWEL

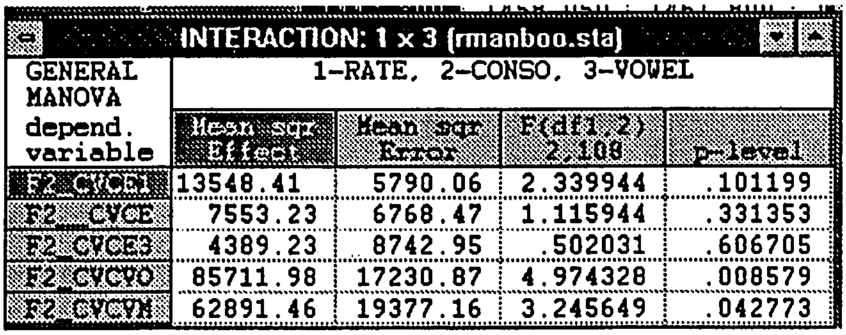
GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
F2_CVCE1	215053.3	5790.06	37.14183	.000000
F2__CVCE	212773.4	6768.47	31.43598	.000000
F2_CVCE3	2314.4	8742.95	.26472	.607949
F2_CVCVO	877230.0	17230.87	50.91039	.000000
F2_CVCVN	30178.4	19377.16	1.55742	.214742

TABLE D5.3: RATE X CONSONANT INTERACTION; D2



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
F2_CVCE1	4106.7	5790.06	.70927	.401548
F2_CVCE	3381.4	6768.47	.49958	.481206
F2_CVCE3	16969.4	8742.95	1.94092	.166429
F2_CVCVO	210840.8	17230.87	12.23623	.000682
F2_CVCVM	7824.7	19377.16	.40381	.526473

TABLE D5.4: RATE X VOWEL INTERACTION; D2



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL Mean sqr Effect	Mean sqr Error	F(df1,2) 2,108	p-level
F2_CVCE1	13548.41	5790.06	2.339944	.101199
F2_CVCE	7553.23	6768.47	1.115944	.331353
F2_CVCE3	4389.23	8742.95	.502031	.606705
F2_CVCVO	85711.98	17230.87	4.974328	.008579
F2_CVCVM	62891.46	19377.16	3.245649	.042773

D2 showed significant Wilks' lamda for the main effect of rate, the rate x consonant interaction and the rate x vowel interaction (see Table D5). Univariate analysis revealed significant F ratios at schwa onset, schwa midpoint and vowel onset, as a function of rate (see Table D5.2). The rate x vowel interaction was significant at the vowel parts (vowel onset and vowel midpoint) (see Table D5.4).

TABLE D5.5: Planned comparisons; Contrastive disyllables at fast rate; D2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F= 7.0727, p<.00902	F= 5.5914, p<.01984	F=.0265, p<.8711	F= 57.44, p<.000000*	F=42.43, p<.00001*
/∂bib/>/∂bub/	F=2.39833, p<.12439	F= 3.1211, p<.08011	F= .42311, p<.51677	F= 22.426, p<.000007*	F= 59.60, p<.00001*
/∂bab/>/∂bub/	F= 1.233874, p<..269122	F= .35754, p<.551127	F=.237997, p<.626645	F=8.083, p<.0053	F=1.4553, p<.2303
/∂did/>/∂dad/	F=3.6149, p<.05993	F=.7707, p<.38195	F=23567, p<.628335	F= 3.3284, p<.07086	F= 16.36, p<.0001*
/∂did/>/∂dud/	F=.09887, p<.753799	F=3.7871, p<.05425	F=4.851, p<.029755	F=27.850, p<.000001*	F= 76.166, p<.00001*
/∂dud/>/∂dad/	F=2.51811 p<.11547	F=1.1409, p<.28734	F=7.22511, p<.008328	F=11.922, p<.00079*	F= 21.93, p<.00001*

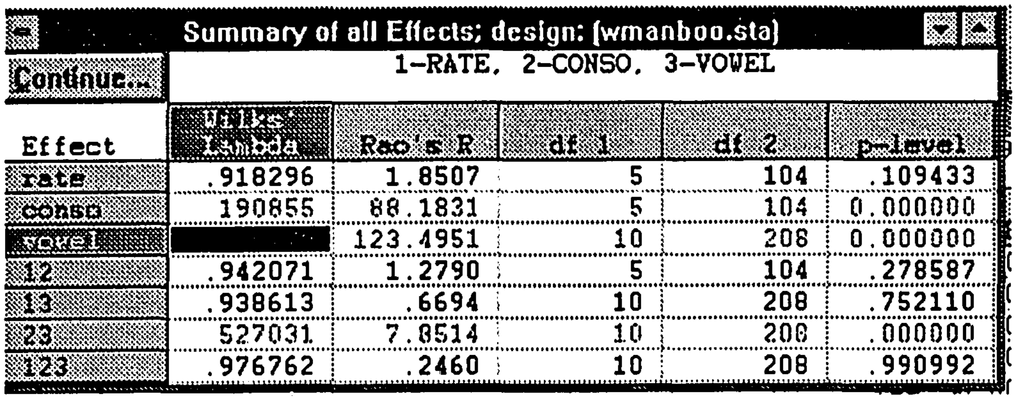
TABLE D5.6: Planned comparisons; Contrastive disyllables at normal vs. fast rate; D2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=4.361, p<.039121	F= 1.06512, p<.304356	F=1.4536, p<.23058	F=7.7287, p<.00641	F=.7809, p<.3788
/∂bib/>/∂bub/	F= 1.73554, p<.1905	F=1.4244 , p<.23529	F=1.7756, p<.1855	F= 001986, p<.964534	F= 38462, p<.53645
/∂bab/>/∂bub/	F=.5943, p<.442445	F= 02606, p<.8705	F=01608, p<.8993	F=7.4828, p<.00728	F= 2.262, p<.13553
/∂did/>/∂dad/	F= .882133, p<.3497	F=1.36988, p<.24441	F= .01135, p<.91536	F=1.2094, p<.27389	F=5.459, p<.0213
/∂did/>/∂dud/	F=.3337, p<.56469	F= 3171, p<.57453	F=04538, p<.83168	F=.000118, p<.99137	F=68942, p<.4082
/∂dud/>/∂dad/	F= 130724, p<.7184	F=3.0051 , p<.0858	F= .102142, p<.74989	F=1.23337, p<.26922	F=2.268, p<.1349

DEAF TALKER D3

The overall results of a 2x2x3 multivariate factorial analysis are presented in Tables D6, D6.2 below:

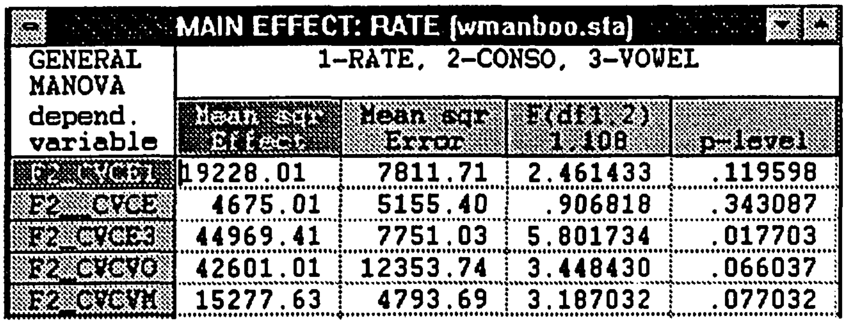
TABLE D6: SUMMARY TABLE; D3



1-RATE, 2-CONSO, 3-VOWEL

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
rate	.918296	1.8507	5	104	.109433
conso	190855	88.1831	5	104	0.000000
vowel	[illegible]	123.4951	10	208	0.000000
12	.942071	1.2790	5	104	.278587
13	.938613	.6694	10	208	.752110
23	527031	7.8514	10	208	.000000
123	.976762	.2460	10	208	.990992

TABLE D6.2: MAIN EFFECT OF RATE; D3



1-RATE, 2-CONSO, 3-VOWEL

GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,108	p-level
[illegible]	19228.01	7811.71	2.461433	.119598
F2_CVCE	4675.01	5155.40	.906818	.343087
F2_CVCE3	44969.41	7751.03	5.801734	.017703
F2_CVCVO	42601.01	12353.74	3.448430	.066037
F2_CVCVH	15277.63	4793.69	3.187032	.077032

In Table D6, the Wilks' lamda was not significant for the main effect of rate or its interactions. Univariate results on the main effect of rate (Table D6.2) revealed a significant F2 change at schwa offset, across vowel types. At this point, we observed decreases of all F2 means, across alveolar disyllables.

We conclude that this talker does not show significant spectral changes as a function of increased rate. This finding is not surprising since the durational shortening of the stressed syllables at fast rate was only 15%. Note that D3's durational changes were statistically significant along all portions of the utterance "a CVC again".

TABLE D6.5: Planned comparisons; Contrastive disyllables at normal vs. fast rate; D3

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bib/>/∂bab/	F=.033296, p<.855554	F=.247682, p<.619724	F=.326163, p<.569114	F= .16437, p<.68596	F=.0666, p<.7968
/∂bib/>/∂bub/	F=.143835, p<.705242	F=.031816, p<.858766	F= 1.3460, p<.248537	F=.00034, p<.98528	F=.6948, p<.4064
/∂bab/>/∂bub/	F= .315539, p<.575465	F=101956, p<.750111	F=.346999, p<.557047	F=.14972, p<.69956	F=1.1916, p<.27744
/∂did/>/∂dad/	F=9.3402, p<.00283*	F= 9.163, p<.00309*	F=2.6671, p<.105357	F=22.048, p<.00001*	F=85.436, p<.00001*
/∂did/>/∂dud/	F=8.747, p<.00381*	F=7.2903, p<.0081	F= 3.6576, p<.05846	F= 40.31, p<.00001*	F=758.1, p<.00001*
/∂dud/>/∂dad/	F= .0097, p<.92158	F= .1069, p<.7443	F= 0781, p<.78049	F=2.735, p<.1011	F=334.50, p<.00001*

TABLE D6.6: Planned comparisons; Contrastive disyllables at normal vs. fast rate; D3

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bib/>/∂bab/	F=.0333, p<.85555	F=.24768, p<.6197	F=32616, p<.56911	F=164373, p<.68596	F= 0666, p<.7968
/∂bib/>/∂bub/	F=.143835, p<..705242	F=031816, p<.85877	F=1.346, p<.24854	F=.000342, p<.98528	F=6948, p<.406
/∂bab/>/∂bub/	F= .31554, p<.57546	F=.10196 , p<.75011	F=.34699 , p<.55704	F=.14972, p<.699565	F=1.192 , p<.277
/∂did/>/∂dad/	F=.09033, p<.76434	F=08195, p<.77522	F=76182, p<.3847	F=.138913, p<.7101	F= 1.736, p<.190
/∂did/>/∂dud/	F=.000003, p<.998576	F=.21385, p<.64469	F=2.0849, p<.151653	F=.117537, p<.73239	F=.1142 , p<.7360
/∂dud/>/∂dad/	F=.091404, p<..762981	F=.031035, p<.860491	F= .326163, p<.569114	F=.000892, p<.976223	F=.95981, p<.3294

2. COARTICULATION OF CONSONANT CONTEXT

HEARING TALKER H1

Table D1b presents planned comparisons of a 2x2x3 MANOVA, where the F2 values were examined as a function of rate, consonant type and vowel type. In the planned comparisons of Table D1b, disyllables of identical vowel composition and contrastive consonant context were compared at fast rate only, to examine changes in temporal anticipation of consonant context.

TABLE D1b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar
Consonant Context; H1

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bab/-/∂dad/	F=7.13, p<.0087	F=23.6506, p<.000004*	F=22.8357, p<.000006*	F=334.06, p<.00001*	F=2.6332, p<.10757
/∂bib/-/∂did/	F=3.067, p<.0827	F=11.45711, p<.000994*	F=15.93248, p<.00012*	F=3.661, p<.0583	F=1.90340, p<.170548
/∂bub/-/∂dud/	F=4.778, p<03099	F=18.848, p<..000032*	F=31.082, p<.000000*	F=1135.84, p<.00001*	F=351.314, p<.000000*

Another set of planned comparisons was performed on the 2x2x3 MANOVA for talker H1 (see Table D1.2b). The F2 values were compared across two contrastive conditions, i..e. normal vs. fast rate and bilabial vs. alveolar context. With the exception of vowel midpoint for contrastive disyllables containing [u] (/∂bub/-/∂dud/), no significant coarticulation changes were noted as a function of anterior consonant contexts. Thus, the spatial changes inferred by the increased F2 separation between contrastive disyllables were not significant. In addition, no significant changes were noted in the extent of temporal anticipation of consonant context.

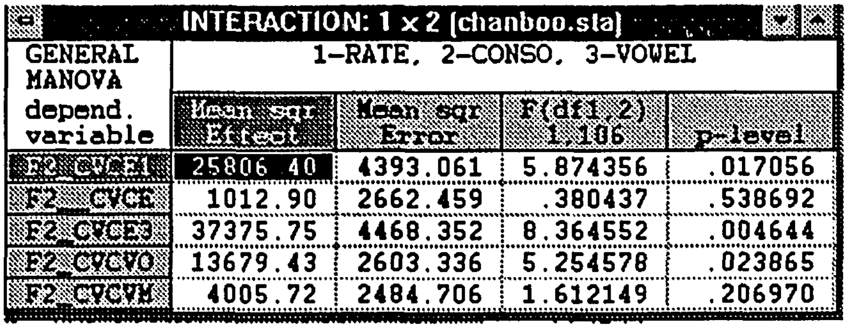
TABLE D1.2b: Planned Comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar Consonant Context; H1

Comparison	∂1	∂2	∂3	T onset	V midpoint
/∂bab/-/∂dad/, Normal vs. Fast	F=.1936, p<.6585	F=.042, p<.837	F=1.657, p<.2007	F=4.19687, p<.04292	F=.4537, p<.50201
/∂bib/-/∂did/, Normal vs. Fast	F=2.16, p<.144	F=2.94, p<.089	F=1.778, p<.18516	F=.6499, p<.4219	F=.14688, p<.70229
/∂bub/-/∂dud/, Normal vs. Fast	F=.096, p<7578	F=.038, p<.8456	F=.0500, p<.8231	F=.00324, p<.9547	F=14.077, p<.00028*

HEARING TALKER H2

The above findings pertain to the rate x consonant interaction of the 2x2x3 MANOVA (see Table D2.3b).

TABLE D2.3b: RATE X CONSONANT INTERACTION; H2



GENERAL MANOVA depend. variable	1-RATE, 2-CONSO, 3-VOWEL			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,106	p-level
F2_CVCE1	25806.40	4393.061	5.874356	.017056
F2_CVCE	1012.90	2662.459	.380437	.538692
F2_CVCE3	37375.75	4468.352	8.364552	.004644
F2_CVCVO	13679.43	2603.336	5.254578	.023865
F2_CVCVM	4005.72	2484.706	1.612149	.206970

In Table D2.3b, there was a significant consonant x rate interaction at schwa onset, schwa offset and vowel onset, indicating higher F2 values for the alveolar context at those measurement points as a function of increased rate.

TABLE D2.4b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar Consonant Context; H2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bab/-/∂dad/	F=128.651, p<.000000*	F=285.32, p<.00001*	F=196.81, p<.000000*	F=432.3693, p<.000000*	F=22.739, p<.00001*
/∂bib/-/∂did/	F=28.7738, p<.000000*	F=100.384, p<.00001*	F=118.629, p<.000000*	F=.2452, p<.62147	F=.0986, p<.75413
/∂bub/-/∂dud/	F=98.914, p<000000*	F=260.159, p<.00001*	F=266.807, p<.000000*	F=659.3057, p<.000000*	F=376.24, p<.00001*

TABLE D2.4: Planned comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar context; H2

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bab/-/∂dad/ Normal vs. Fast	F=8.571, p<.00418*	F=7.13054, p<.008772	F=.49226, p<.48446	F=.144631, p<.704481	F=3.728, p<.0562
/∂bib/-/∂did/ Normal vs. Fast	F=1.35523, p<.24698	F=8.63563, p<.00405*	F=14.83, p<.000202*	F=1.25842, p<.264484	F=.659, p<.4186
/∂bub/-/∂dud/ Normal vs. Fast	F=5.70218, p<018714	F=1.6016, p<..20845	F=.237425, p<.627078	F=6.23896, p<.014037	F=1.09, p<.299

HEARING TALKER H3

TABLE D3b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar Consonant Context; H3

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bab/-/∂dad/	F=83.49, p<.000000*	F=131.827, p<.000000*	F=93.7, p<.00001*	F=488.5, p<.00001*	F=27.005, p<.000001*
/∂bib/-/∂did/	F=47.1284, p<.000000*	F=85.3799, p<.000000*	F=79.045, p<.00001*	F=19.297, p<.000026*	F=7.04714, p<.00913
/∂bub/-/∂dud/	F=111.442, p<000000*	F=186.098, p<..000000*	F=121.34, p<.00001*	F=1043.89, p<.00001*	F=728.545, p<.00001*

TABLE D3.2b: Planned comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar context; H3

Comparison	∂1	∂2	∂3	**T onset**	**V mid**
/∂bab/-/∂dad/ Normal vs. Fast	F=.31089, p<.57829	F=.082543, p<.774431	F=.608474, p<.437069	F=2.26258, p<.13545	F=3.4246, p<.06696
/∂bib/-/∂did/ Normal vs. Fast	F=.160434, p<.689549	F=.977729, p<.32497	F=.286048, p<.593864	F=1.71237, p<.19346	F=2.990, p<.0866
/∂bub/-/∂dud/ Normal vs. Fast	F=2.003787, p<159784	F=1.4968, p<..223829	F=.4335, p<.511678	F=.47336, p<.49292	F=4.070, p<.0461

The planned comparisons in Table D3.2 examine increases in coarticulation of consonant context as a function of rate. No significant increases were observed. A nearly significant result was noted at vowel midpoint for /∂bub/-/∂dud/ pair, as a function of rate.

DEAF TALKER D1

TABLE D4b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar Consonant Context; D1

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/	F=1.97015, p<.163301	F=2.33218, p<.129648	F=33.66, p<.00001*	F=78.029, p<.00001*	F=2.292, p<.1329
/∂bib/-/∂did/	F=.71072, p<.401069	F=2.59565, p<.110077	F=23.997, p<.00001*	F=1.0186, p<.3151	F=.3115, p<.5779
/∂bub/-/∂dud/	F=2.10662, p<.149562	F=.62025, p<..432679	F=51.27, p<.00001*	F=1.784, p<.18446	F=61.909, p<.00001*

TABLE D4.2b: Planned comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar context; D1

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/, Normal vs. Fast	F= .04366, p< .83488	F= 1.0646, p< .30447	F=.00076, p< .97797	F= 1.002, p< .3191	F= .04516, p< .8321
/∂bib/-/∂did/, Normal vs. Fast	F=.0517, p< .82055	F=1.13576, p< .2889	F= .3660, p< .54645	F= 1.327, p< .25198	F= .473514, p< .49285
/∂bub/-/∂dud/, Normal vs. Fast	F=.0018, p< .9657	F=2.515, p< .1157	F= 1.797, p< .183	F= .20663, p< .65033	F=4.6809, p< .0327

DEAF TALKER D2

TABLE D5b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar Consonant Context; D2

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/	F=.42559, p<.51555	F=13.78, p<.00033*	F=97.22, p<.00001*	F=44.95, p<.00001*	F=1.1445, p<.2871
/∂bib/-/∂did/	F=.01119, p<.915945	F=4.955, p<.0281	F=84.86, p<.000000*	F=.9035, p<.343	F=1.957, p<.1646
/∂bub/-/∂dud/	F=1.27336, p<.261639	F=.4188, p<.0431	F=58.67, p<.00001*	F=.167, p<.68	F=5.790, p<.0178

TABLE D5.2b: Planned comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar context; D2

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/, Normal vs. Fast	F=1.011, p< .3168	F=2.776, p< .09855	F=.3443, p< .55858	F=.8424, p< .3607	F= 72572, p< .39616
/∂bib/-/∂did/, Normal vs. Fast	F= .02056, p< .88626	F=.287, p< .5929	F=2.842, p< .0947	F=6.750, p< .01068	F=.36104, p< .5491
/∂bub/-/∂dud/, Normal vs. Fast	F=.3556, p< .55218	F=.0088, p< .9251	F= 0197, p< .8886	F=6.4656, p< .0124	F=.72186, p< .3974

DEAF TALKER D3

TABLE D6b: Planned Comparisons; Fast rate; Bilabial vs. Alveolar Consonant Context; D3

Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/	F=.639, p<.426	F=9.4864, p<.00263*	F=51.88, p<.00001*	F=14.304, p<.0002*	F=2.681, p<.10445
/∂bib/-/∂did/	F=12.725, p<.0005*	F=27.27, p<.00001*	F=48.961, p<.00001*	F=27.486, p<.00001*	F=10.017, p<.00201*
/∂bub/-/∂dud/	F=.0018, p<.9657	F=2.9766, p<.0873	F=5.436, p<.0215	F=83.79, p<.00001*	F=3.3061, p<.07179

TABLE D6.2b: Planned comparisons; Normal vs. Fast rate; Bilabial vs. Alveolar context; D3

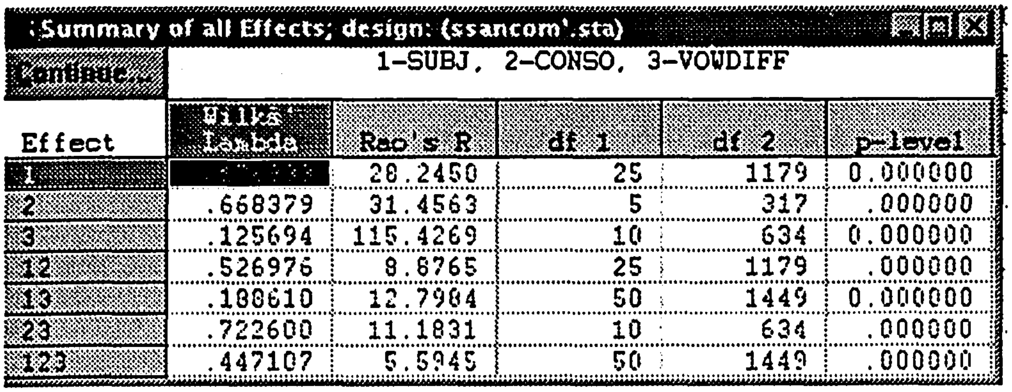
Comparison	∂1	∂2	∂3	T onset	V mid
/∂bab/-/∂dad/, Normal vs. Fast	F=.53274, p< .4670	F=.21385, p< .64469	F=1.0223, p< .314223	F=.2465, p< .62057	F=.0789, p< .77933
/∂bib/-/∂did/, Normal vs. Fast	F=.06095, p< .8054	F=.0630, p< .80226	F=1.7235, p< .1920	F= .07934, p< .77874	F=1.79699 , p< .18289
/∂bub/-/∂dud/, Normal vs. Fast	F=.018002, p< .893517	F=.0011, p< .97371	F=1.059, p< .3057	F= .00635, p< .93665	F= .02856 p< .86612

Another set of planned comparisons was performed, on the same MANOVA, to examine whether F2 differences, in alveolar vs. bilabial disyllables, increase in magnitude as a function of rate. Overall, the F2 mean differences between bilabial and alveolar disyllables did not significantly increase as a function of rate.

APPENDIX E

BETWEEN-GROUP COMPARISON OF COARTICULATION IN DISYLLABLES

TABLE E1: SUMMARY OF MAIN EFFECTS



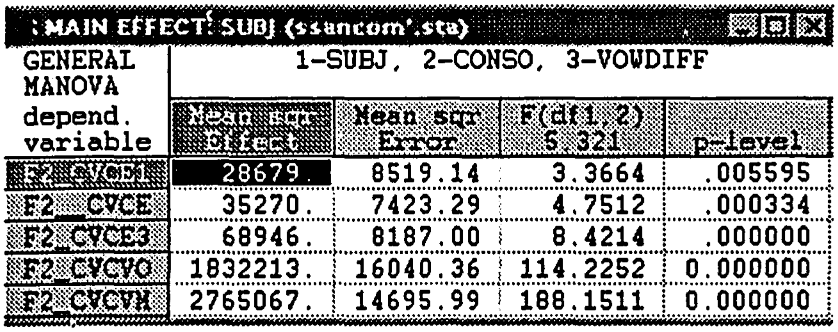
:Summary of all Effects; design: (ssancom'.sta)

1-SUBJ, 2-CONSO, 3-VOWDIFF

Effect	Wilks' Lambda	Rao's R	df 1	df 2	p-level
1	[illegible]	28.2450	25	1179	0.000000
2	.668379	31.4563	5	317	.000000
3	.125694	115.4269	10	634	0.000000
12	.526976	8.8765	25	1179	.000000
13	.188610	12.7984	50	1449	0.000000
23	.722600	11.1831	10	634	.000000
123	.447107	5.5945	50	1449	.000000

UNIVARIATE TESTS

TABLE E2: MAIN EFFECT OF SUBJECT

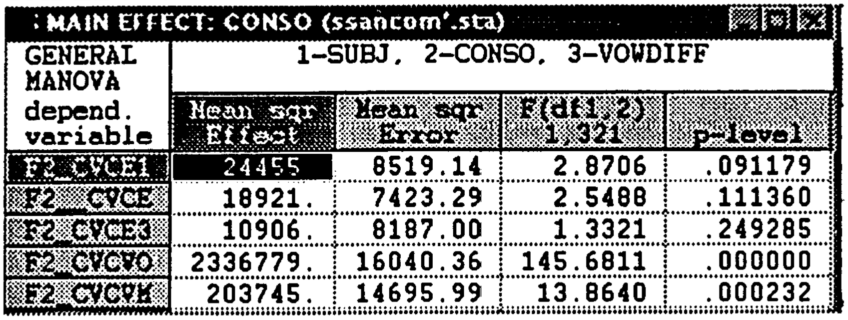


:MAIN EFFECT: SUBJ (ssancom'.sta)

1-SUBJ, 2-CONSO, 3-VOWDIFF

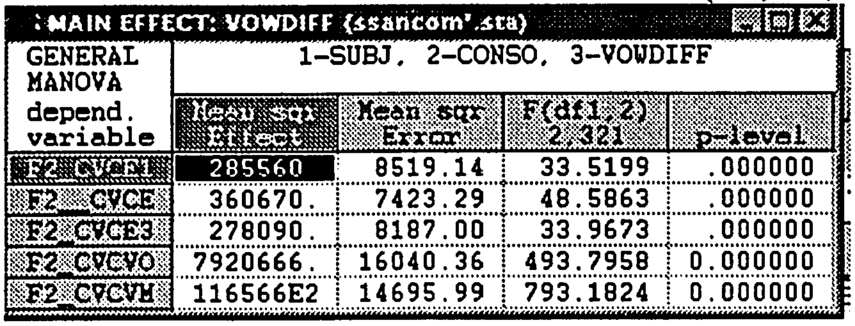
GENERAL MANOVA depend. variable	Mean sqr Effect	Mean sqr Error	F(df1,2) 5,321	p-level
F2_CVCE1	28679.	8519.14	3.3664	.005595
F2_CVCE	35270.	7423.29	4.7512	.000334
F2_CVCE3	68946.	8187.00	8.4214	.000000
F2_CVCVO	1832213.	16040.36	114.2252	0.000000
F2_CVCVM	2765067.	14695.99	188.1511	0.000000

TABLE E3: MAIN EFFECT OF CONSONANT



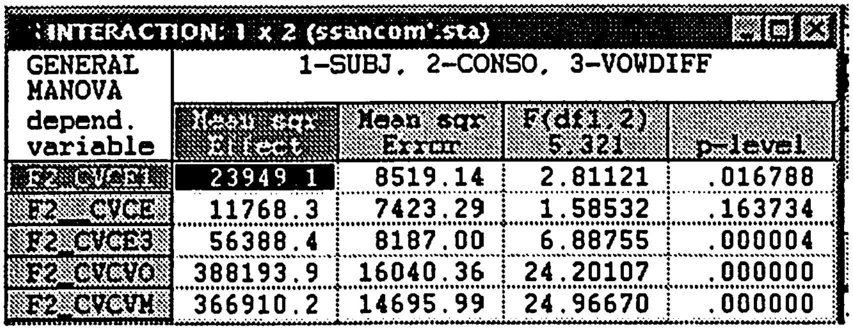
GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 1,321	p-level
F2_CVCE1	24455	8519.14	2.8706	.091179
F2_CVCE	18921.	7423.29	2.5488	.111360
F2_CVCE3	10906.	8187.00	1.3321	.249285
F2_CVCVO	2336779.	16040.36	145.6811	.000000
F2_CVCVM	203745.	14695.99	13.8640	.000232

TABLE E4: MAIN EFFECT OF VOWEL PAIRS (I-U, I-A, A-U)



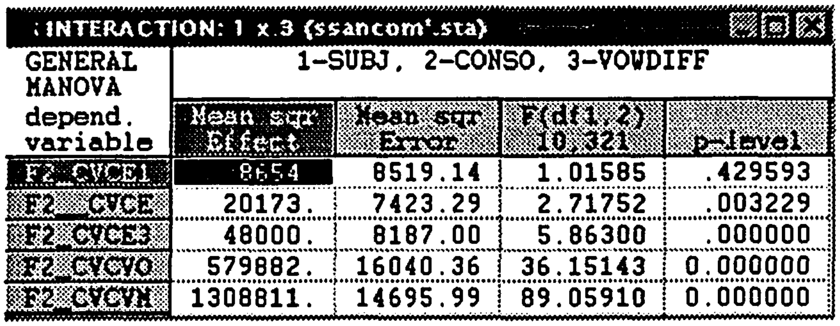
GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 2,321	p-level
F2_CVCE1	285560	8519.14	33.5199	.000000
F2_CVCE	360670.	7423.29	48.5863	.000000
F2_CVCE3	278090.	8187.00	33.9673	.000000
F2_CVCVO	7920666.	16040.36	493.7958	0.000000
F2_CVCVM	116566E2	14695.99	793.1824	0.000000

TABLE E5: INTERACTION OF SUBJECT X CONSONANT



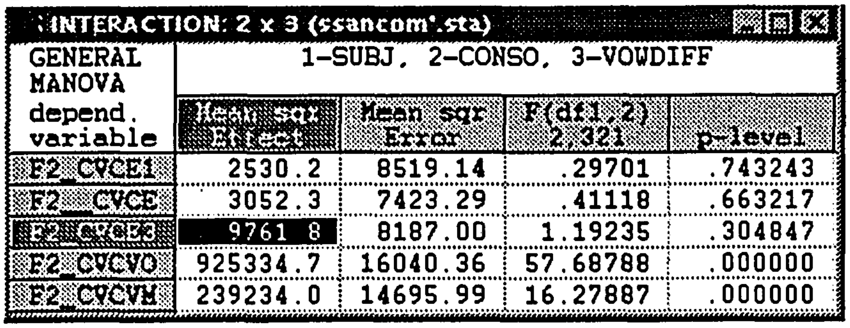
GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF			
	Mean sqr Effect	Mean sqr Error	F(df1,2) 5,321	p-level
F2_CVCE1	23949.1	8519.14	2.81121	.016788
F2_CVCE	11768.3	7423.29	1.58532	.163734
F2_CVCE3	56388.4	8187.00	6.88755	.000004
F2_CVCVO	388193.9	16040.36	24.20107	.000000
F2_CVCVM	366910.2	14695.99	24.96670	.000000

TABLE E6: INTERACTION OF SUBJECT X VOWEL PAIR



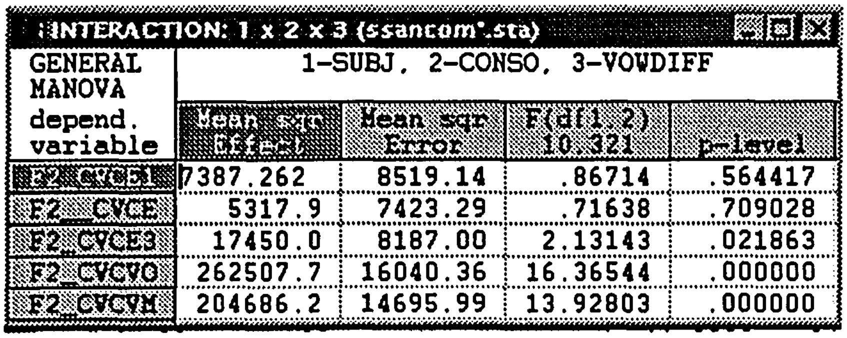
GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF Mean sqr Effect	Mean sqr Error	F(df1,2) 10,321	p-level
F2_CVCE1	8654	8519.14	1.01585	.429593
F2__CVCE	20173.	7423.29	2.71752	.003229
F2_CVCE3	48000.	8187.00	5.86300	.000000
F2_CVCVO	579882.	16040.36	36.15143	0.000000
F2_CVCVM	1308811.	14695.99	89.05910	0.000000

TABLE E7: INTERACTION OF CONSONANT X VOWEL PAIR



GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF Mean sqr Effect	Mean sqr Error	F(df1,2) 2,321	p-level
F2_CVCE1	2530.2	8519.14	.29701	.743243
F2__CVCE	3052.3	7423.29	.41118	.663217
F2_CVCE3	9761.8	8187.00	1.19235	.304847
F2_CVCVO	925334.7	16040.36	57.68788	.000000
F2_CVCVM	239234.0	14695.99	16.27887	.000000

TABLE E8: INTERACTION OF SUBJECT X CONSONANT X VOWEL PAIR



GENERAL MANOVA depend. variable	1-SUBJ, 2-CONSO, 3-VOWDIFF Mean sqr Effect	Mean sqr Error	F(df1,2) 10,321	p-level
F2_CVCE1	7387.262	8519.14	.86714	.564417
F2__CVCE	5317.9	7423.29	.71638	.709028
F2_CVCE3	17450.0	8187.00	2.13143	.021863
F2_CVCVO	262507.7	16040.36	16.36544	.000000
F2_CVCVM	204686.2	14695.99	13.92803	.000000

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