To the Graduate Council:

I am submitting herewith a dissertation written by Paul A. Dagenais entitled "Vowel Parameter Shifts Due to Decreased Stress for Repeated Words in Passages." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Sciences.

Carl W. Asp, Major Professor

We have read this dissertation
and recommend its acceptance:

Accepted for the Council:

Vice Provost
and Dean of the Graduate
School

VOWEL PARAMETER SHIFTS DUE TO DECREASED STRESS FOR REPEATED WORDS IN PASSAGES

A Dissertation

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Degree

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Paul A. Dagenais

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ABSTRACT

Ten experienced speakers read four paragraphs, each with ten repetitions of a high information CVC (consonant-vowel-consonant) word. Speakers were checked by judges to ensure that they spoke accurately. In three word repetitions (1st, 5th and 10th), which had identical syntactic contexts, vowels were analyzed spectrographically. For peak fundamental frequency, duration and peak amplitude, there were significant differences ($p < 0.05$) among repetitions for averaged values across three of the four CVC words. There was a significant ($p < 0.05$) decreasing linear trend across repetitions for all three parameters. When the raw data was rank ordered using difference limen criteria, results were the same. When the rank-order data was averaged across parameters, the decreasing trend was emphasized with significant differences between successive repetitions.

There were no differences among repetitions for F1 and F2 formant onset and target frequencies. As speakers spoke all target words accurately, all formant parameters remained within acoustic limits for vowel identity.

Correlations of the acoustic measures among the seven parameters were insignificant. The sample size ($n = 10$) may have been too small to detect any relationships between the parameters.

Trained listeners were not able to consistently rate isolated word repetitions for comparative stress levels. However, when entire passages were used, listeners were able to judge the stress levels of word repetitions. The 1st utterance was given the highest stress rating which agreed with the acoustical measures for peak fundamental frequency, duration and peak amplitude. Stress ratings for the 5th and 10 utterances were similar and also agreed with acoustical measures for the same parameters. It was concluded that perceptions of comparative stress required speech units greater than syllable length. Recommendations for future studies were presented.

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CHAPTER I

INTRODUCTION

Syllable stress is important for oral communication because it conveys cues of syntactic and semantic structure. Without stress information, utterances may be misinterpreted (Morgan,1984). For example, the difference between the noun/verb pair contract vs contract, is made by shifting the syllable stress from the first syllable in the noun to the second syllable in the verb.

Lehiste (1970) defines syllable stress as being indicated by an increase in effort being used by speakers. Early physiological studies showed that increases in syllable stress were produced by increasing respiratory effort during exhalation. Recent studies have examined movements and positionings of the articulators under varying conditions of stress. These studies which involved electromyography (EMG), cineradiography and motion pictures, have shown that there are differential movements of the articulators depending upon the stress requirements (Kent and Netsell, 1971; Keuhn and Moll, 1976; Gay, Ushijima, Hirose and Cooper, 1974; Harris, 1978). When syllable stress increases, the amplitude of EMG signals increases, as measured by electrode attachment to the articulatory muscles. Further, the cineradiographic and motion picture studies have shown that the lips, jaw

and tongue displace more towards traditionally accepted articulatory positions, as identified in isolated productions, as syllable stress increases.

From acoustical studies, researchers have reported that an increase in syllable stress is usually accompanied by an increase in intensity (dB), fundamental frequency (Hz) and duration (msec) (Fry, 1955, Lindblom, 1963). While increases in intensity and fundamental frequency can be attributed to an increase in physiological effort, an increase in duration appears to be a linguistically determined parameter for indicating differing levels of syllable stress (Lehiste, 1970). Other studies have shown changes in the formant frequencies of vowels with changes in the requirements of syllable stress (Gay, 1978) but without changes in vowel identity.

Researchers have reported that changes in syllable stress are independent of changes in speech rate (Gay, 1978; Harris, 1978; Tuller, Harris and Kelso, 1982). More specifically, articulator positions needed for syllable stress are not affected or limited by the velocity capabilities of the articulators. In these studies, speakers used specified levels of syllable stress and rates of speech as required by the researchers.

Several studies have measured parameter changes while speaking in "normal" contexts. In normal contexts the speaker is not controlled by the experimenter. He is

recorded while reading a passage or conversing with others. These studies have shown that:

1) speech styles (e.g. conversational speech, reading of a list of words) can determine the F2, but not the F1, target position of vowels (Ladefoged, Kameny and Brackenbridge, 1976),

2) repeating the same word while reading, results in a decrease in the duration of the vowels in those words (Umeda, 1975) and

3) repeating high content words in context shows a decrease in both vowel duration and fundamental frequency in those words (Coker, Umeda and Bowman, 1973).

Coker et al. (1973) stated that a decrease in fundamental frequency and duration are usually accompanied by a decrease in semantic stress for these high content words. Vowel intensity does not decrease in words that are repeated in context (Lehiste, 1970; Linngard, 1985).

None of the studies mentioned above have investigated all the acoustic parameters (duration, fundamental frequency, amplitude and formant frequencies) within one study. This information is needed for speakers who are not controlled by an experimenter. Repeating a key word while reading a passage seems to give the speaker the freedom and still allows the experimenter the control of the text. Then, the experimenter can measure the parameters of the vowels in these key words. Vowels are

good indicators of stress (Harris, 1978) and parameters measured from readings appear to be good indicators of parameters measured from spontaneous speech (Anderson and Cooper, 1986).

Measurements of the changes in the acoustic parameters of speech and the relationships among these changes should have many applications in speech science. One application is the area of synthetic speech. Unfortunately, the synthetic speech systems which are capable of producing unlimited speech vocabularies, also have poor intelligibility (Bowe, 1984). The main reason for poor intelligibility is the lack of suprasegmental information during variations in stress patterns. This information is needed to produce better computer software (Linngard, 1985; Morgan, 1984). A comprehensive study on acoustic parameters of speech while reading a passage should provide some of this information.

In order to obtain normal speech, Coker et al. (1973) and Umeda (1975) recorded subjects reading texts. They analyzed vowels in repeated words which had, according to them, initially high stress levels due to their unpredictable nature. Changes in the acoustical parameters were cited as an indicator of a decrease in the level of syllable stress. Also, studies using recorded texts by Dagenais (1981 and 1983) showed a relationship between a decrease in vowel duration and a shift in F2 target

formant frequency away form its initial position. This relationship seems to be evident in situations where readers are not controlled by the experimenter, but it is not so clear when the experimenter controls the reader's performance. A more detailed description of the above mentioned studies is found in Appendix A (Review of the Literature).

While there are changes in the perceptual levels of syllable stress, the intent of this investigation was to measure the changes in the acoustic parameters of talkers' speech. The present study did not emphasize changes in the perception of stress, even though they do occur and will be generally described.

Purpose

The purpose of this investigation was to measure the parameters of vowels in repeated words as made by speakers reading a passage and to determine if there were any trends corresponding to earlier findings of decreases across repetitions. The parameters under investigation were fundamental frequency (F0), duration, amplitude, and the onset and target frequencies of the F1 and F2 formants of vowels. A secondary purpose was to determine the relationship (correlation) among these parameters. Finally, although no specific research question was proposed, a desciption of listener perceptions of

comparative stress across the repetitions was completed. As a result, the following experimental questions were tested:

1) For vowels in key words that are repeated while reading a Passage are there changes among the 1st, 5th and 10th repetition for:

a) peak F0 (Hz),

b) duration (msec),

c) amplitude (dB),

d) onset of F1 formant frequency (Hz),

e) onset of F2 formant frequency (Hz),

f) target of F1 formant frequency (Hz),

g) target of F2 formant frequency (Hz).

2) For the above listed vowel parameters, are there linear trends across the 1st, 5th and 10th repetitions of each key word?

3) For the 1st, 5th and 10th repetition of these vowels, are there correlations between:

a) F0 and duration,

b) F0 and amplitude,

c) F0 and F1 onset frequency,

d) F0 and F2 onset frequency,

e) F0 and F1 target frequency,

f) F0 and F2 target frequency,

g) duration and amplitude,

h) duration and F1 onset frequency,

i) duration and F2 onset frequency,

j) duration and F1 target frequency,

k) duration and F2 target frequency,

l) amplitude and F1 onset frequency,

m) amplitude and F2 onset frequency,

n) amplitude and F1 target frequency,

o) amplitude and F2 target frequency.

CHAPTER II

METHOD

The purpose of this study was to measure the acoustic parameters of vowels in key words that are repeated while reading a passage, determine the relationships between these parameters and describe listener perceptions of comparative stress across the word repetitions. To accomplish this, the following procedures were used.

Subjects

Speakers were ten male college students between the ages of 21 and 32 years. All had good speaking skills and had prior experience in recording and/or broadcasting situations. The speakers were enrolled at the University of Tennessee, Knoxville, six as Broadcasting majors and four as Speech and Hearing majors. None of the speakers reported a history of hearing problems.

Materials

The experimenter constructed four passages, with each passage containing one target word (See Appendix B). All of the target words (peak, thief, coupe and shoes) satisfied the following criteria:

1) All four test words were consonant-vowel-consonant (CVC) monosyllables,
2) Two of the words ("thief" and "peak") had the vowel /i/ with a high front tongue position, whereas the other two ("shoes" and "coupe") had the vowel /u/ with a high back tongue position. High vowels were used because a shift in articulator position would have been in one direction.
3) With the exception of /z/ in "shoes," both the pre- and post-vocalic consonants were voiceless. Voiceless consonants facilitated the determination of vowel duration, onset frequencies of the formants and the phoneme boundaries.
4) The consonants were either fricatives or plosives in order to evaluate their affect upon vowel duration and other parameters. Peterson and Lehiste (1960) reported that vowel duration was dependent upon the type of surrounding consonants.

Each passage contained ten repetitions of the target word (See Appendix B). The 1st (first), 5th (middle) and 10th (last) repetitions were used for spectrographic analysis. Each of these key words has an identical context, e.g. the object of a preposition at the end of a declarative sentence. The key words are underlined in each passage. The speakers read copies of these passages in which the key words were not underlined or identified.

Procedures and Equipment

High quality tape recordings were made in a sound treated room. A 1-inch Bruel and Kjaer (B&K) microphone (model 4145) was postioned 3 inches from the speakers' lips. Readings were recorded on a reel-to-reel Ampex tape recorder (model AG 440B) set at a speed of 7.5 i.p.s.

Each of the ten speakers was given the four passages prior to the recording sessions and was requested to become familiar with each passage prior to recording. At the time of recording, the speakers read all passages, aloud, in a natural way, using a normal rate and inflection pattern. Each speaker read a practice passage during which the experimenter set the recording level at -5.0 on the VU meter. If the experimenter decided that any of the target words were mispronounced during the recording sessions, the passage in which the error occurred was re-recorded. In other words, speakers were checked to ensure they spoke accurately. The order of the four passages was randomized for each speaker.

Accuracy of Speaker's Utterances

Phrases which contained the key words (1st, 5th and 10th repetitions) from the four passages were re-recorded onto Language Master cards. The phrases for the four passages were "at our peak," "of a thief," "was

the coupe" and "interest in shoes" and are indicated by parentheses in the passages of Appendix B. To ensure that all key words were spoken correctly, two experienced speech pathologists listened to the Language Master recordings and transcribed, independently, all key words in phonetic symbols, e.g. /pik/. Results of the transcriptions showed that all key words were spoken as intended.

Acoustical Analysis

The original tape recordings were used for the acoustical analysis. Narrow and broad-band spectrograms with amplitude displays and power-spectra of each key word were made using the Kay Digital Sona-Graph, 7800. The following parameters for each vowel were measured using the procedures outined in Appendix C:

1) Duration,
2) Peak fundamental frequency,
3) Peak amplitude,
4) F1 and F2 onset frequencies,
5) F1 and F2 target frequencies.

Perceptual Judgements of Stress

Two perceptual procedures were completed for this study. For the first procedure, the Language Master cards were cut with a scissor to eliminate everything but the key word. The key words for each passage were then taped

together, in a randomized order, such that they could be replayed as a single recording of the three isolated words in triplicate.

Three experienced speech pathologists were trained to identify contrasting levels of stress. Training involved listening to selected recordings in which differences in stress across key words could be noted. Listeners were trained to identify differences in pitch, duration, loudness and vowel quality. Their task was to assign comparative ratings of low, mid or high stress to the key words contained on each recording. The training was continued until the judgements made by the three listeners to ten (25%) randomly chosen recordings had at least 90% agreement. When this criterion was met, each of the listeners independently rated all recordings.

The second procedure involved similar ratings of stress for the three key words for the passages with the word "coupe". Two speech pathologists who had not participated in the first procedure, listened independently to entire passages as replayed from the original tape recordings. They were told to listen for differences in stress as indicated by differences in pitch, duration and loudness but were otherwise untrained.

Reliability Measures

Two types of reliability measures were done for this study, within-examiner reliability and between-examiner reliability. For the within-examiner reliability, a set of ten randomly chosen spectrograms was re-measured by the experimenter. For the between-examiner reliability, a second set of ten randomly chosen spectrograms was measured by a second experienced person. Pearson Product-Moment correlation coefficients were completed for the parameters for the within and between-examiner conditions. These are reported in Table 2.1. The magnitudes of the r values were 0.855 or higher. Because of these high correlation coefficients, it was concluded that there was excellent consistency for re-measurements of all parameters in both conditions.

Table 2.1. Pearson Product-Moment Correlation Coefficients for Within- and Between-Examiner Reliability measures for all experimental conditions.

Parameter	Within-Experimenter r value	Between-Experimenter r value
1. Duration	0.989*	0.995*
2. Amplitude	0.964*	0.971*
3. Fundamental Frequency	0.959*	0.855*
4. F1 Formant Onset Frequency	0.976*	0.943*
5. F2 Formant Onset Frequency	0.995*	0.918*
6. F1 Formant Target Frequency	0.994*	0.976*
7. F2 Formant Target Frequency	0.999*	0.879*

*Significant at 0.05.

CHAPTER III

RESULTS

Results obtained to answer the experimental questions are presented in the following three sections. In the first section (Acoustical Results: Tests of Difference), the first and second experimental questions are addressed by examining for differences between repetitions and for the presence of any trends across the repetitions. The second section (Acoustical Results: Tests of Correlation), pertains to the third experimental question regarding relationships between the parameters. In the final section (Perceptual Results), descriptive statistics from comparative stress ratings across repetitions as determined by listeners are presented.

Acoustical Results: Tests of Difference

The results of the vowel parameters for the four repeated words for the 10 speakers are found in Appendix D. For the Peak Fundamental Frequency, means and standard deviations for the three repetitions of the four words are shown in Table 3.1 and Figure 3.1. Averages across the four words were not presented because, as explained below, the results from the word "peak" were extreme and could have been misleading as to overall trends. As can be seen in Figure 3.1, peak fundamental frequencies decreased as

Table 3.1. Mean values and standard deviations for Peak Fundamental Frequencies in Hertz (Hz) for the three repetitions of the four test words.

	Frequency (Standard Deviation)		
Word	1st Repetition	5th Repetition	10th Repetition
peak	130.5 (26.4)	128.1 (13.2)	144.5 (27.1)
thief	138.9 (22.6)	134.2 (19.3)	133.2 (27.8)
coupe	141.1 (34.2)	132.6 (33.5)	131.5 (22.6)
shoes	142.6 (31.8)	138.4 (27.9)	137.2 (30.7)

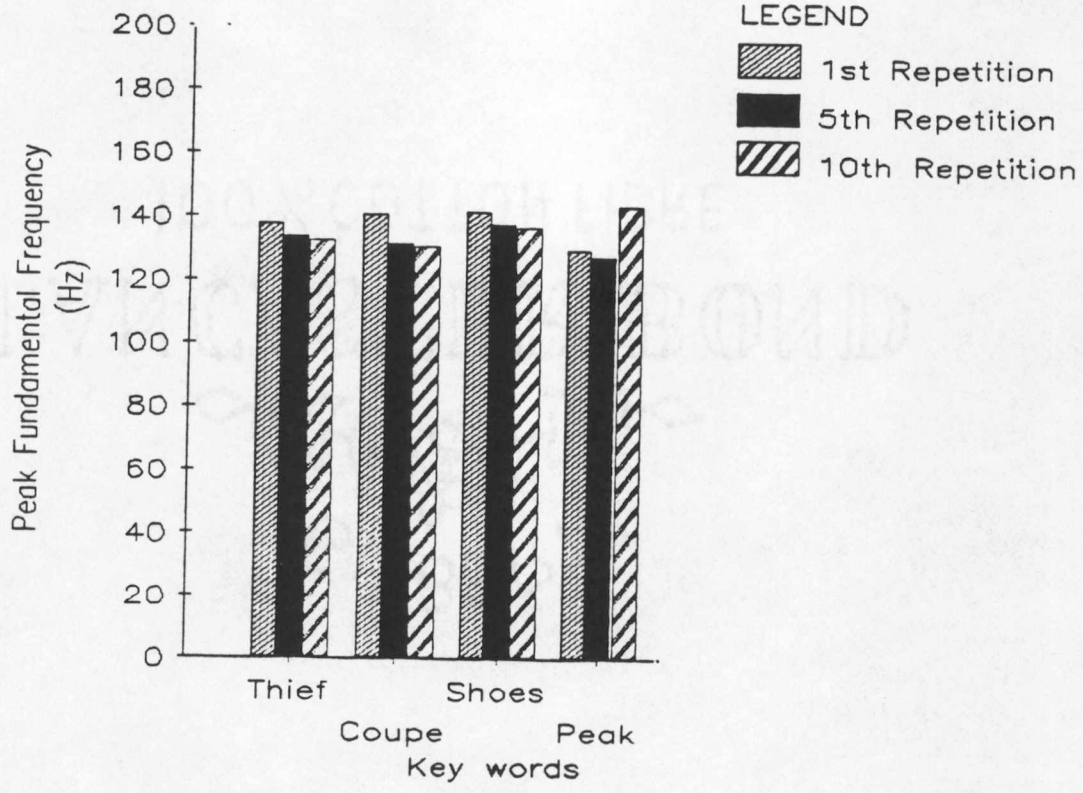


Figure 3.1. Mean values for Peak Fundamental Frequencies in Hertz (Hz) for three repetitions of the four test words.

repetitions increased for three of the four words ("thief," "coupe" and "shoes"). For the word "peak," there was an increase in the final (10th) repetition which was of such magnitude as to influence the averaged measures. The 5th repetition had the lowest value of all utterances. A one-way ANOVA with repeated measures showed no significant differences for the words "thief," "coupe" and "shoes;" however there was a significant difference for the word "peak" (See Table 3.2, $p < 0.05$). For the word "peak," the 1st and 5th repetitions were significantly different from the 10th, but were not different from each other. The difference between the 10th repetition and the 1st and 5th rpetitions was of such magnitude as to make the relationship linear ($p < 0.05$) between these three repetitions for the word "peak."

For Vowel Duration, the mean values and standard deviations are shown in Table 3.3 and Figure 3.2. As with peak fundamental frequency, durations decreased as repetitions increased for "thief," "coupe" and "shoes," but not for "peak." For "peak," the 5th repetition was the least for all the measures. There were significant differences (See Table 3.4, $p < 0.05$) among repetitions for three of the four words (peak, thief and shoes). For "peak," the 5th repetition was significantly different (less) than the 1st and 10th repetitions which themselves were not different. For "thief" and "shoes," the 1st

Table 3.2. Results from One-Way Analysis of Variance (ANOVA) with repeated measures for peak fundamental frequency across the three repetitions for the four target words.

Word	Analysis	F Value	Probability
peak	ANOVA	6.22	0.0089*
	Contrast 1-5	0.23	0.6406
	Contrast 1-10	10.03	0.0114*
	Contrast 5-10	8.59	0.0167*
	Linearity	10.03	0.0114*
thief	ANOVA	1.07	0.3629
	Contrast 1-5	1.78	0.2155
	Contrast 1-10	3.32	0.1017
	Contrast 5-10	0.03	0.8638
	Linearity	3.32	0.1017
coupe	ANOVA	1.65	0.2206
	Contrast 1-5	2.72	0.1337
	Contrast 1-10	2.78	0.1657
	Contrast 5-10	0.03	0.8759
	Linearity	2.28	0.1657
shoes	ANOVA	1.14	0.3418
	Contrast 1-5	1.41	0.2652
	Contrast 1-10	1.38	0.2702
	Contrast 5-10	0.17	0.6940
	Linearity	1.38	0.2702

* significant at 0.05.

Table 3.3. Mean values and standard deviations for Duration in Milliseconds (msec) for the three repetitions of the four test words.

	Duration (Standard Deviation)		
Word	1st Repetition	5th Repetition	10th Repetition
peak	143.7 (21.2)	128.7 (14.8)	145.0 (18.1)
thief	174.4 (26.8	160.6 (26.6)	158.7 (19.8)
coupe	136.9 (15.4)	134.4 (11.5)	129.4 (17.2)
shoes	258.1 (29.3)	243.1 (30.1)	234.4 (27.5)

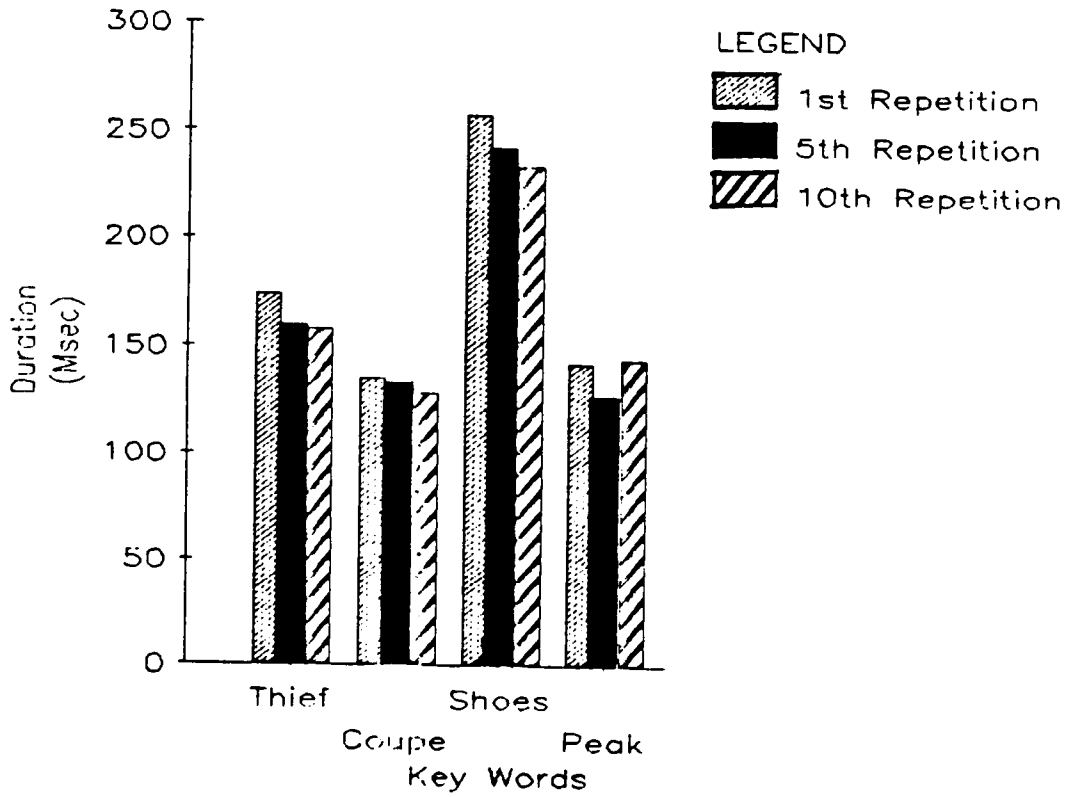


Figure 3.2. Mean values for Duration in Milliseconds (ms) for three repetitions of the four test words.

Table 3.4. Results from One-Way Analysis of Variance (ANOVA) with repeated measures for duration across the three repetitions for the four target words.

Word	Analysis	F Value	Probability
peak	ANOVA	11.26	0.0070*
	Contrast 1-5	17.05	0.0026*
	Contrast 1-10	0.14	0.7136
	Contrast 5-10	13.70	0.0049*
	Linearity	0.14	0.7160
thief	ANOVA	7.61	0.0040*
	Contrast 1-5	12.96	0.0057*
	Contrast 1-10	12.10	0.0070*
	Contrast 5-10	0.16	0.7020
	Linearity	12.10	0.0070*
coupe	ANOVA	1.22	0.3188
	Contrast 1-5	0.24	0.1542
	Contrast 1-10	2.42	0.6370
	Contrast 5-10	1.12	0.1542
	Linearity	2.42	0.1542
shoes	ANOVA	8.51	0.0025*
	Contrast 1-5	6.61	0.0301*
	Contrast 1-10	14.50	0.0042*
	Contrast 5-10	2.66	0.1376
	Linearity	14.50	0.0042*

* significant at 0.05.

repetition was signifcantly different (greater) than the 5th and 10th repetitions which were not different from each other. The relationships across repetitions for both "thief" and "shoes" were linear ($p < 0.05$).

For Peak Vowel Amplitude, means and standard deviations are shown in Table 3.5 and Figure 3.3. Again, results were similar to those obtained for peak fundamental frequency and duration. The values decreased as repetitions increased for three of the four words (thief, coupe and shoes). For the word "peak," the 5th repetition had the least value of all the utterances. Significant differences among repetitions were noted for the words "thief" and "coupe" (See Table 3.6, $p < 0.05$). For "thief," the 1st utterance was different (greater) from the 10th repetition. The 5th repetition was not different from either the 1st or the 10th. The relationship between repetitions for this word was linear ($p < 0.05$). For "coupe," the 1st repetition was different (greater) from the both the 5th and 10th repetitions. The 5th and 10th repetitions were not different. The relationship was also linear ($p < 0.05$).

Mean and standard deviations for F1 formant onset frequencies, F2 formant onset frequencies, F1 formant target frequencies and F2 formant target frequencies are shown in Appendix E (Table E.1) and in Figures 3.4, 3.5, 3.6 and 3.7 respectively. Spectrographic measures are

Table 3.5. Mean values and standard deviations for Peak Amplitude in decibels for the three repetitions of the four test words.

	Peak Amplitude (Standard Deviation)		
Word	1st Repetition	5th Repetition	10th Repetition
peak	2.46 (1.418)	1.64 (1.310)	2.67 (0.749)
thief	2.89 (1.095)	2.51 (0.737)	1.96 (0.901)
coupe	3.28 (1.547)	2.84 (1.646)	2.18 (1.458)
shoes	3.27 (1.032)	2.73 (1.263)	2.29 (1.383)

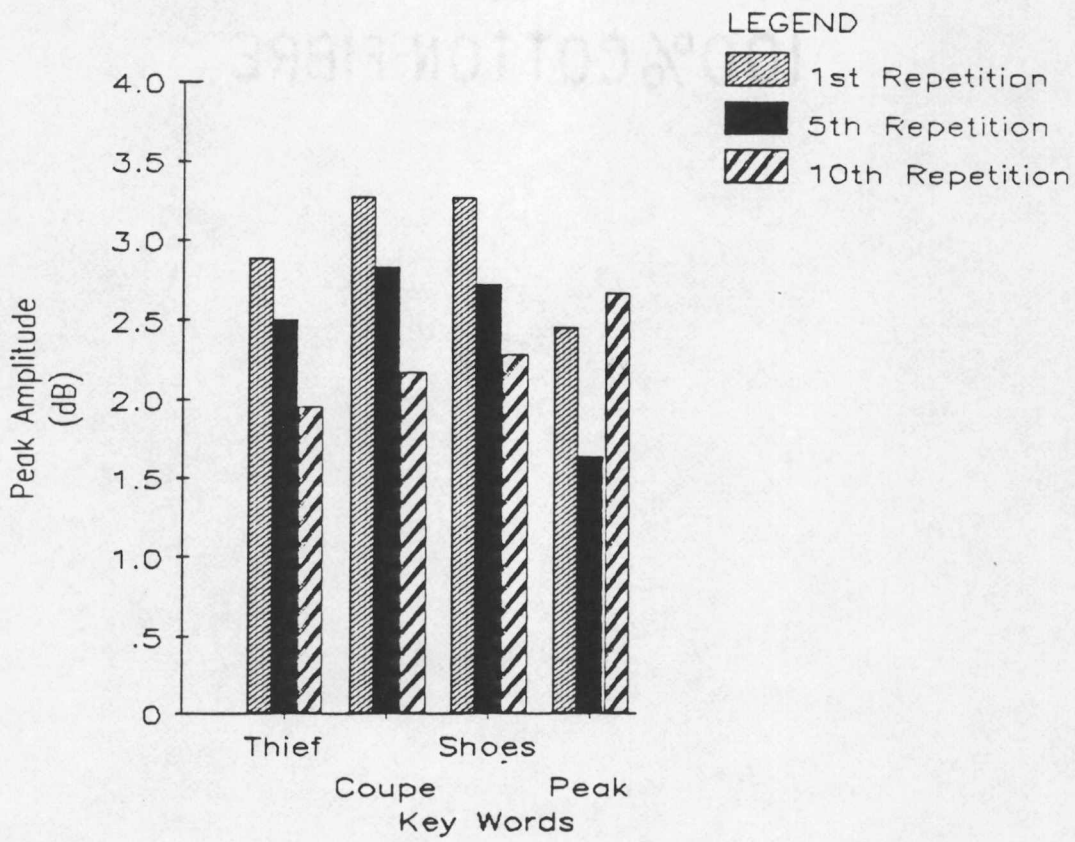


Figure 3.3. Mean values for Peak Amplitude in Decibels (dB) for three repetitions of the four test words.

Table 3.6. Results from One-Way Analysis of Variance (ANOVA) with repeated measures for peak amplitude across the three repetitions for the four target words.

Word	Analysis	F Value	Probability
peak	ANOVA	1.90	0.1789
	Contrast 1-5	2.87	0.1244
	Contrast 1-10	0.12	0.7393
	Contrast 5-10	3.50	0.0941
	Linearity	0.12	0.7393
thief	ANOVA	4.80	0.0213*
	Contrast 1-5	1.83	0.2057
	Contrast 1-10	8.12	0.0191*
	Contrast 5-10	3.46	0.0957
	Linearity	8.12	0.0191*
coupe	ANOVA	4.17	0.0320*
	Contrast 1-5	3.26	0.0450*
	Contrast 1-10	5.61	0.0419*
	Contrast 5-10	2.62	0.1430
	Linearity	5.67	0.0419*
shoes	ANOVA	1.70	0.2136
	Contrast 1-5	1.07	0.3316
	Contrast 1-10	2.49	0.1535
	Contrast 5-10	1.09	0.3314
	Linearity	2.49	0.1535

* significant at 0.05.

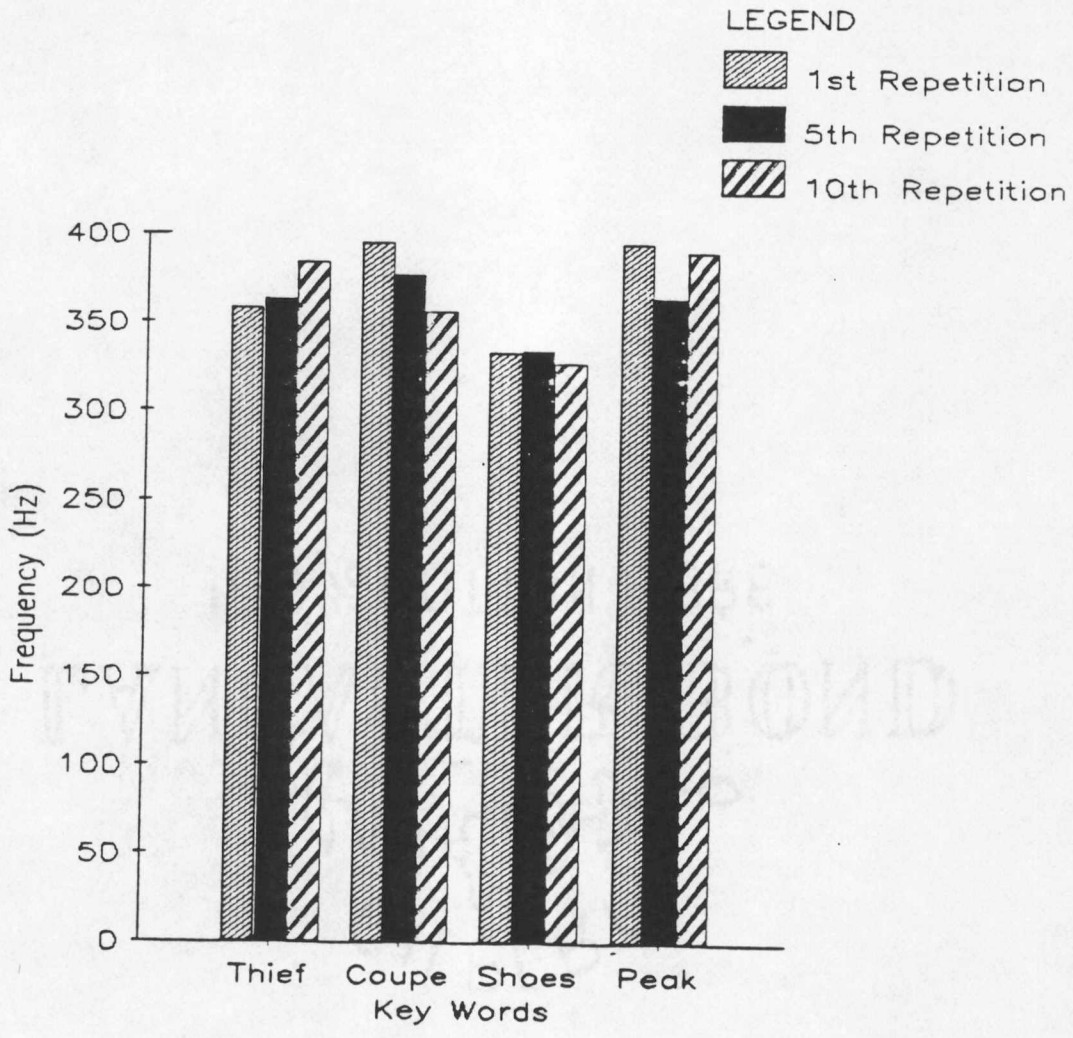


Figure 3.4. Mean values for F1 Formant Onset Frequencies in Hertz (Hz) for three repetitions of the four test words.

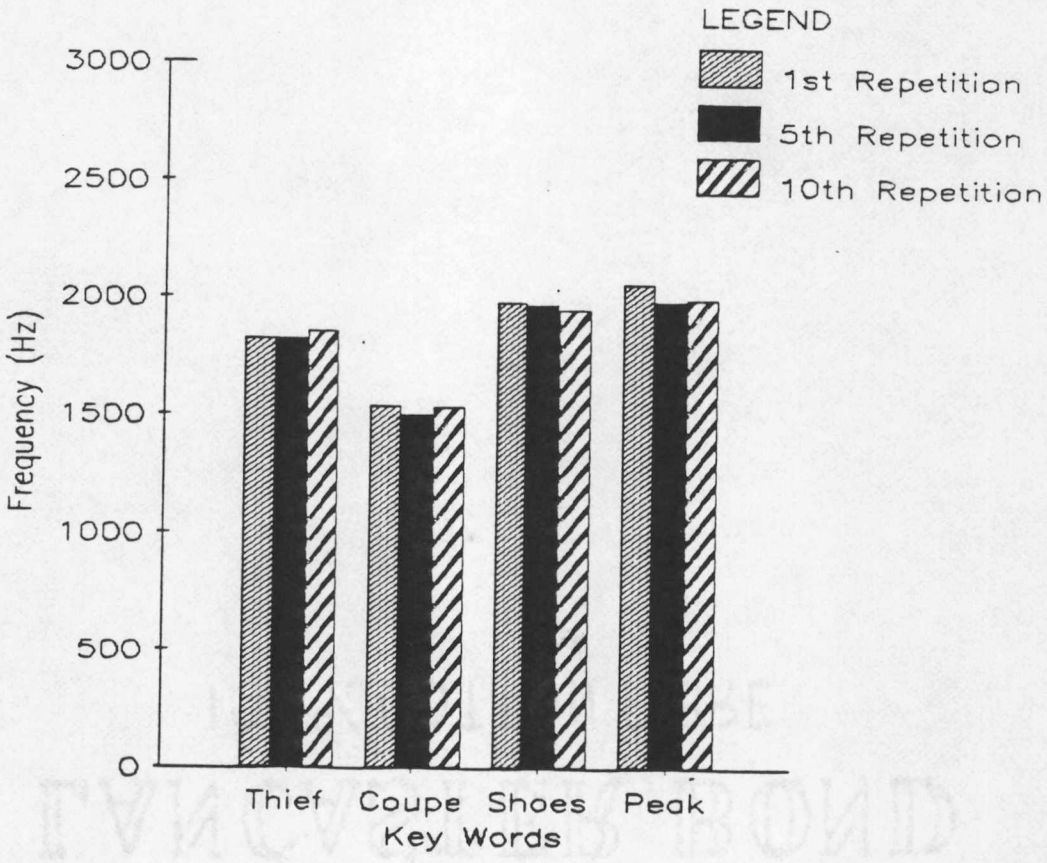


Figure 3.5. Mean values for F2 Formant Onset Frequencies in Hertz (Hz) for three repetitions of the four test words.

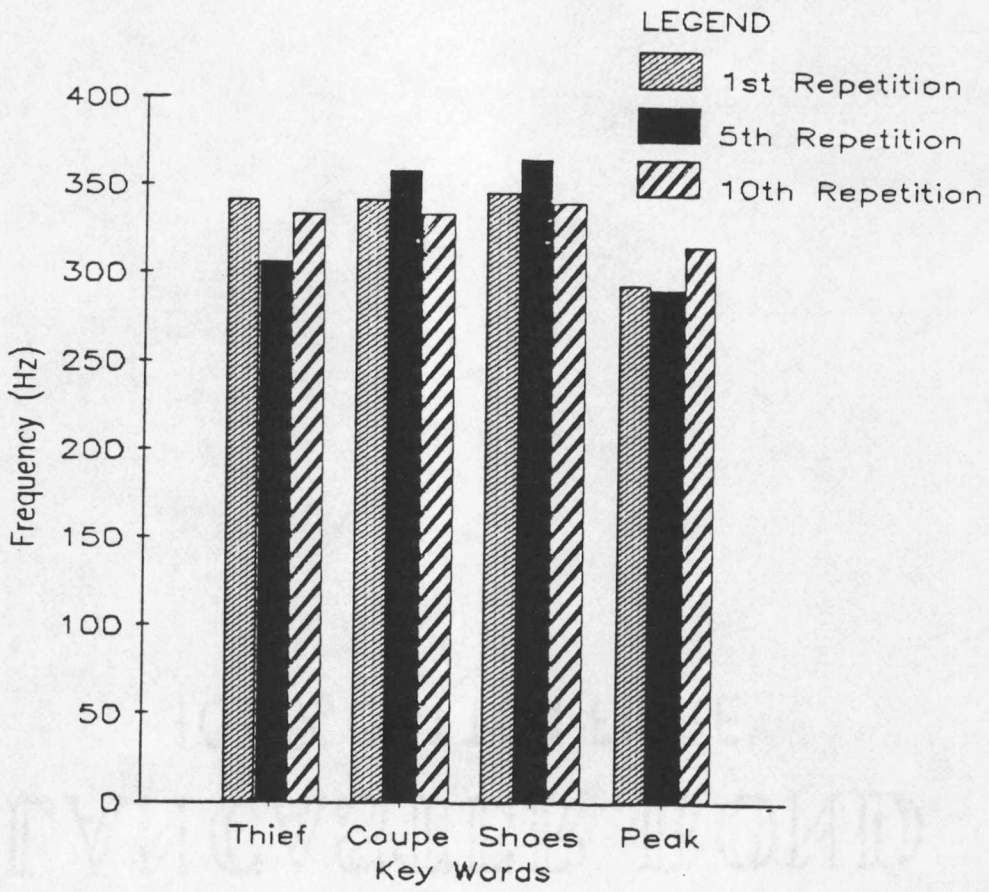


Figure 3.6. Mean values for F1 Formant Target Frequencies in Hertz (Hz) for three repetitions of the four test words.

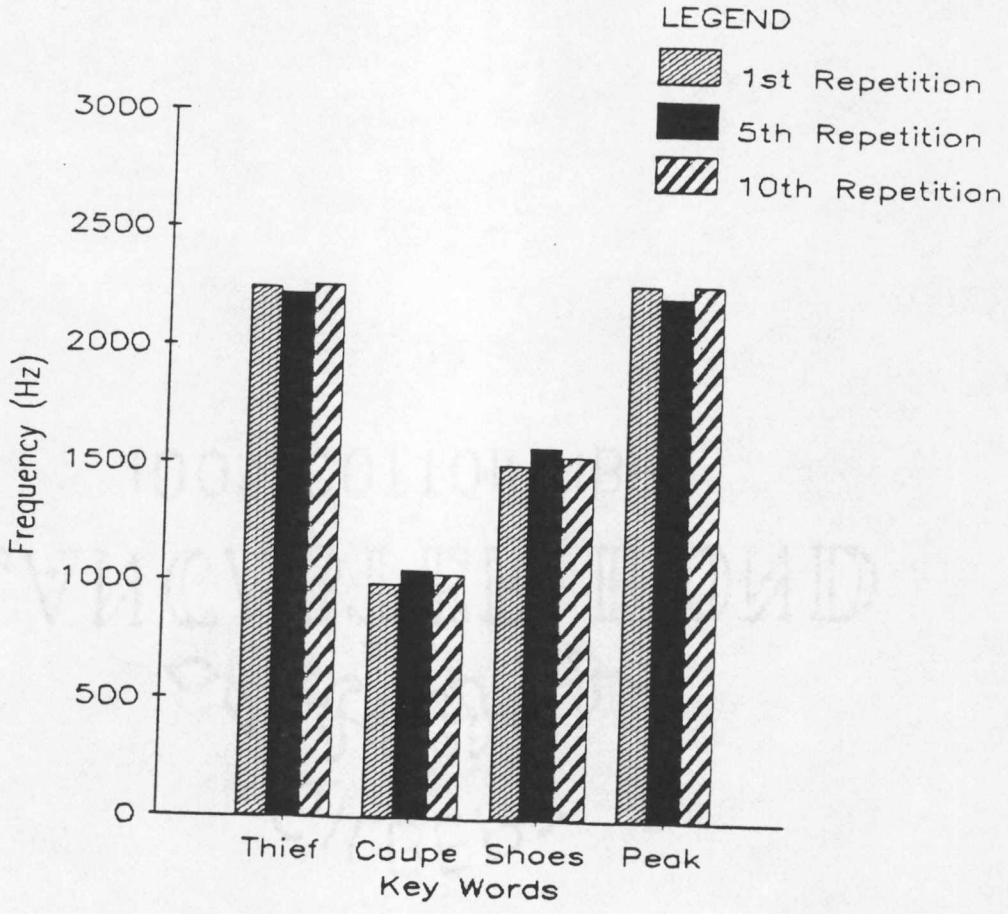


Figure 3.7. Mean values for F2 Formant Target Frequencies in Hertz (Hz) for three repetitions of the four test words.

shown in Appendix E (Tables E.2, E.3, E.4 and E.5). As can be seen in the figures, there were no consistent patterns for more than two of the four words. For the F1 formant, there were no significant differences for any of the four words with regard to onset or target frequencies. For the F2 formant, two measures (both for the word "shoes") showed significance ($p < 0.05$); a difference among repetitions of the target frequencies, with the 1st (lower) and 5th (higher) repetitions being different with neither different from the 10th repetitions, and a linear relationship for the onset frequencies. Since the frequency of the formants determines the vowel and 1st, 5th and 10th repetitions were judged to be the same vowel, the formant frequencies were similar for vowel repetitions.

For three of the four target words (thief, coupe and shoes), peak fundamental frequency, duration and peak amplitude decreased as repetitions increased. However, for the word "peak," the measures of the 5th repetition were noticeably reduced which suggested a lack of syllable stress. In order to examine this difference, the tape recordings of the ten "peak" passages were judged by two experienced listeners who were familiar with the purpose of the study. They identified any differences of intonation or stress patterns that were specific to the 5th repetition but not to the 1st or the 10th. For 5 out of 10 passages, the word "function" in the phrase "function our peak" was

given additional stress. Also, 2 of the remaining 5 passages stressed the word "function" but to a lesser degree. With the word "function" receiving more stress, the subsequent phrase "at our peak" received less stress. As a result, peak fundamental frequency, duration and peak amplitude decreased for the 5th repetition of "peak" and increased for the 10th repetition. Because of these discrepancies, the word "peak" was eliminated from further analysis.

Since there were changes across the repetitions of three key words (See Figures 3.1, 3.2 and 3.3), values for "thief," "coupe" and "shoes" were averaged for the parameters of duration, peak amplitude and peak fundamental frequency and the analysis was repeated. Means and standard deviations for the averaged values for duration, amplitude and fundamental frequency are found in Table 3.7 and Figures 3.8, 3.9 and 3.10 respectively. Results from the statistical analyses are shown in Table 3.8. There were significant differences ($p < 0.05$) between repetitions for all three parameters and the relationships were linear ($p < 0.05$). For peak fundamental frequency and duration, the 1st repetition was significantly different (greater) from the 5th and 10th repetitions. The 5th and 10th repetitions were not different. For peak amplitude, the means for the three repetitions were different from each other with a rank order of the 1st, 5th and 10th. The

Table 3.7. Mean values and standard deviations for Averaged Values across three words (thief, coupe, shoes) for Duration in Milliseconds (msec), Peak Amplitude in Decibels (dB) and Peak Fundamental Frequency in Hertz (Hz).

	Mean (Standard Deviation)		
Parameter	1st Repetition	5th Repetition	10th Repetition
Duration	189.41 (18.79)	178.94 (17.27)	173.39 (16.98)
Peak Amplitude	3.116 (0.727)	2.683 (0.479)	2.149 (0.763)
Peak Fundamental Frequency	140.46 (28.32)	134.59 (25.02)	133.55 (24.73)

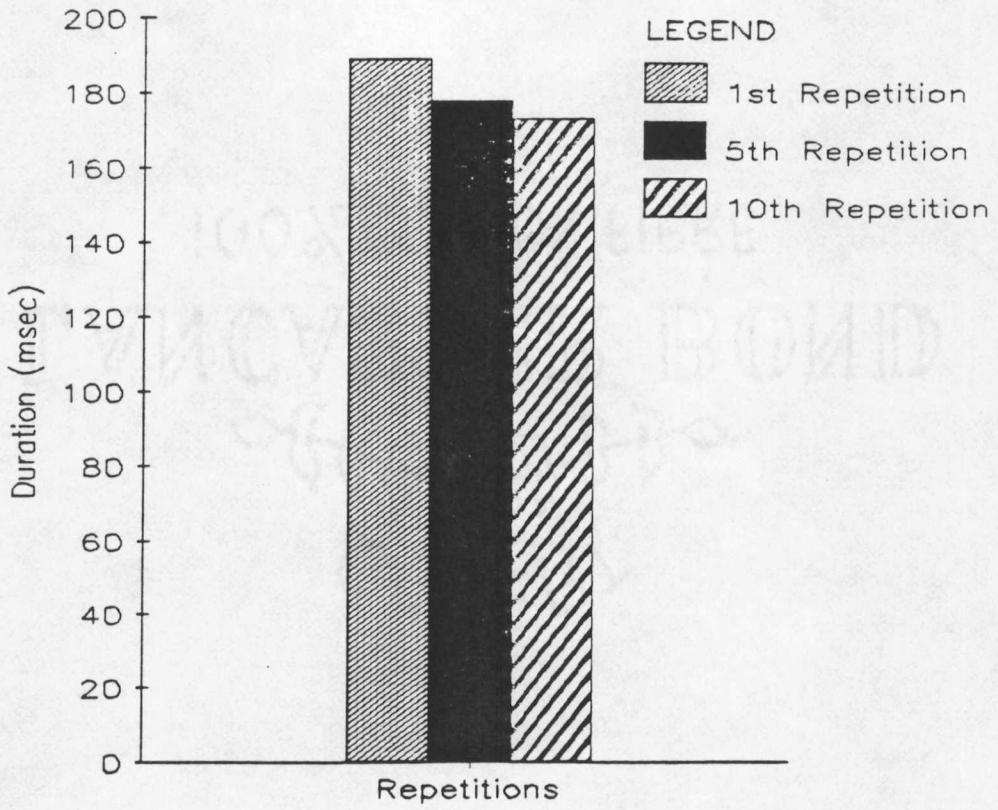


Figure 3.8. Mean values for Duration for averaged values across three words.

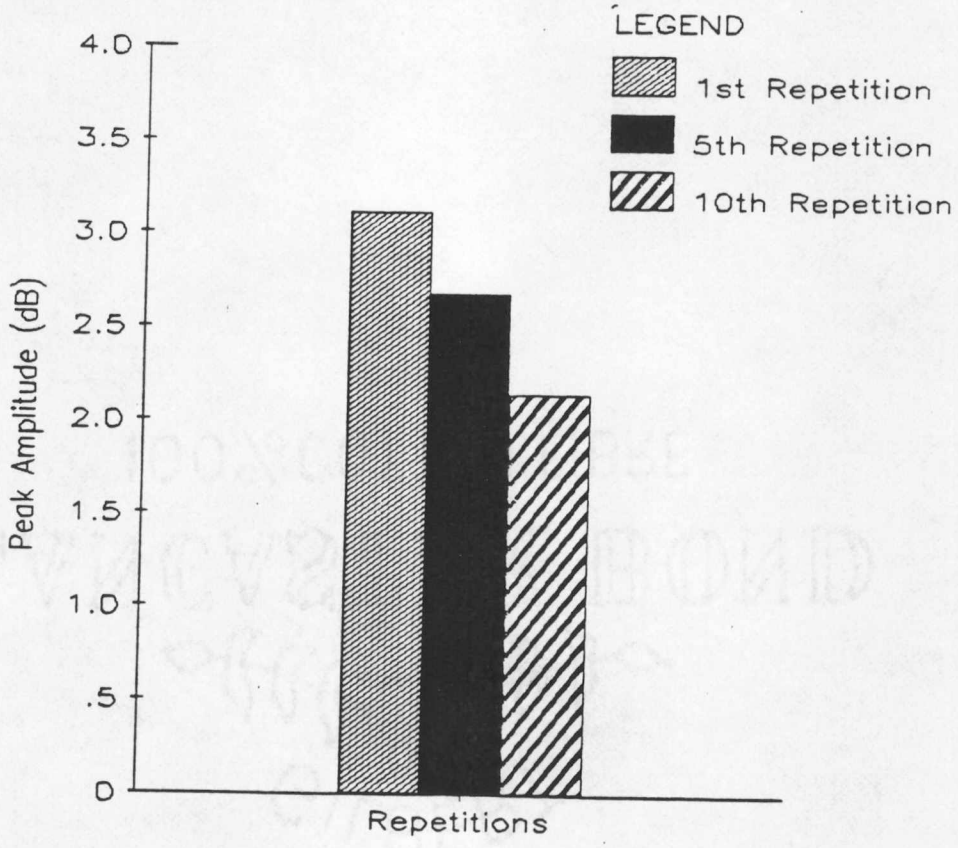


Figure 3.9. Mean values for Peak Amplitude for averaged values across three words.

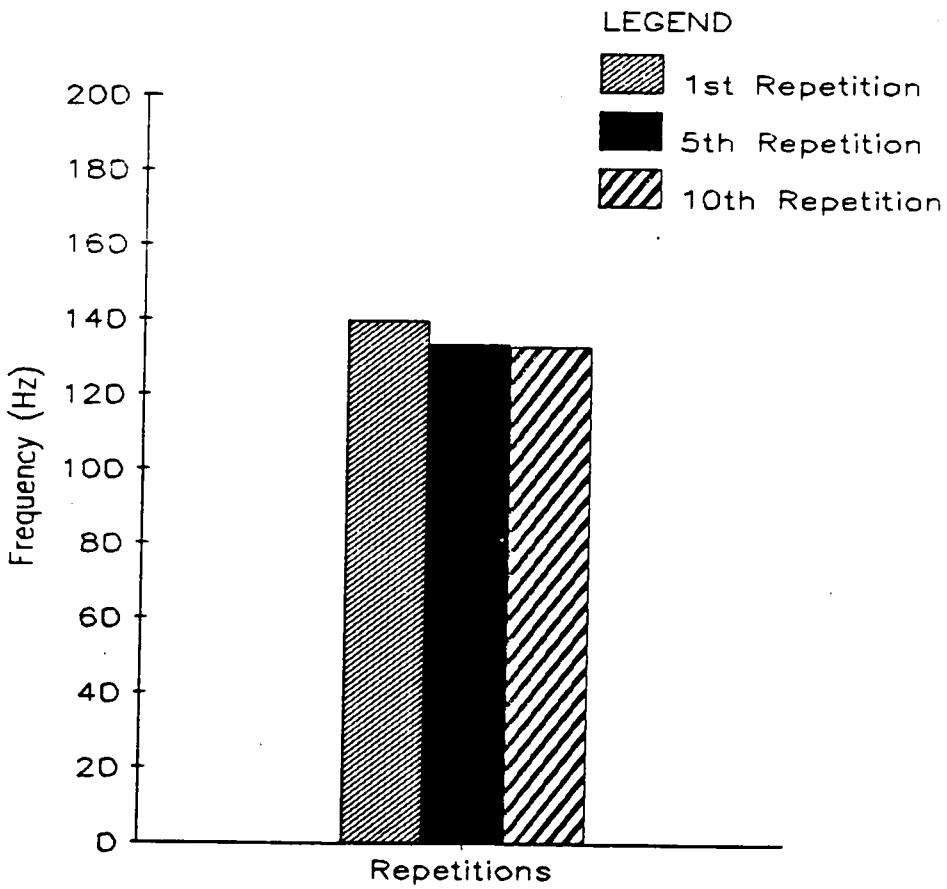


Figure 3.10. Mean values for Peak Fundamental Frequency for averaged values across three words.

Table 3.8. Results from ANOVA procedures for Averaged Vowel Values for Duration, Peak Amplitude and Peak Fundamental Frequency across three words (thief, coupe, shoes).

Parameter	Analysis	F Value	Probability
Duration	ANOVA	14.43	0.0002*
	Contrast 1-5	13.90	0.0047*
	Contrast 1-10	35.60	0.0002*
	Contrast 5-10	2.46	0.1510
	Linearity	35.60	0.0002*
Peak Amplitude	ANOVA	10.54	0.0009*
	Contrast 1-5	4.97	0.0527
	Contrast 1-10	13.03	0.0057*
	Contrast 5-10	11.85	0.0074*
	Linearity	13.03	0.0050*
Peak Fundamental Frequency	ANOVA	5.90	0.0107*
	Contrast 1-5	8.88	0.0155*
	Contrast 1-10	8.49	0.0172*
	Contrast 5-10	0.23	0.6400
	Linearity	8.49	0.0172*

* significant at 0.05.

differences between the means of the 1st and 5th repetitions were greater than the differences between the 5th and the 10th repetitions. This suggested that the greatest stress was used on the 1st utterance of the key words in each passage.

To assess for the possibility of detection of differences across repetitions by listeners, the acoustical data for the three parameters were converted to rank-order data using the perceptual criteria of difference limens. Rank-order data was also used to combine values across the three parameters to check for gestalt trends. This requires further explanation.

There are minimal levels of change which are required before listeners can detect changes in acoustical stimuli. The amount of change needed for a stimulus to be identified as different, 75% of the time, is the difference limen or differential threshold (Minifie, Hixon and Williams, 1973). Difference limens utilized for the vowel parameters in this study were 5 ms for duration (Ruhm, Mencke, Milburn, Cooper and Rose, 1978), 1.0% of the lowest peak fundamental frequency (Flanagan, 1957) and 1 dB for the peak amplitude (Flanagan, 1957). Using these difference limens, the measured values for the 3 parameters were rank ordered in the following manner:

1) For each triplet (1st, 5th and 10th repetition), the lowest value was assigned the arbitrary rating of 1.0.

The next highest value was assigned a rating of 2.0 if it had a difference from the lowest value that was equal to or greater than the difference limen. Similarly, the highest value was rated as 3.0 if the difference between it and the middle value was also equal to or greater than the difference limen.

2) If all values were not different by the required amount, they were all rated as 2.0.

3) If there was a low value different from two higher values which were themselves, not different, the lowest value was assigned a rating of 1.0 while the other two values were both rated as 2.5.

4) If there were two lower non-different values and one higher different value, the two lower values were rated as 1.5 while the higher value was rated as 3.0, and,

5) If the lower value was different from the higher value with the third value between, but not different from either the lower or higher value, then the lower value was rated as 1.0, the middle value as 1.5 and the higher as 2.0. The rank-order data created in this manner are found in Appendix F.

For each parameter (duration, amplitude and fundamental frequency), the rank-order data were averaged across the three words and the analysis repeated. Means and standard deviations for these averaged rankings for the three parameters are found in Table 3.9 and Figures 3.11,

Table 3.9. Mean values and standard deviations for Averaged Values across three words (thief, coupe, shoes) using rank-order data for Duration, Peak Amplitude and Peak Fundamental Frequency.

	Mean (Standard Deviation)		
	1st Repetition	5th Repetition	10th Repetition
Duration	2.561 (0.382)	1.862 (0.383)	1.564 (0.306)
Peak Amplitude	2.279 (0.399)	1.930 (0.250)	1.578 (0.354)
Peak Fundamental Frequency	2.362 (0.232)	1.882 (0.323)	1.779 (0.336)

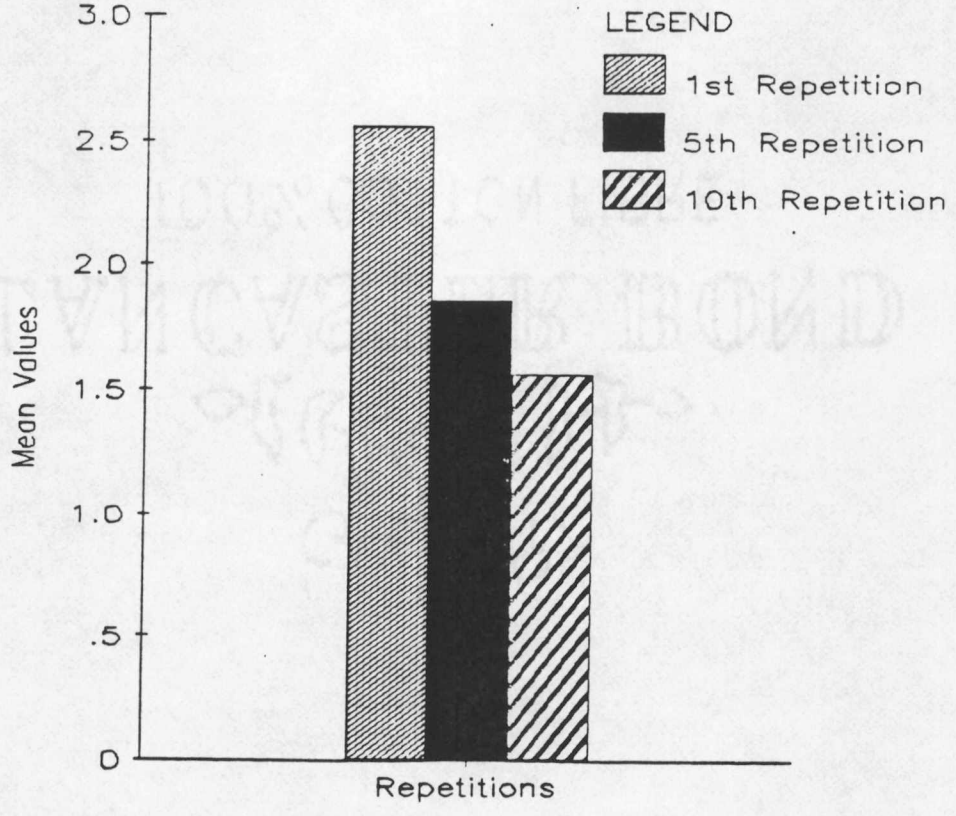


Figure 3.11. Mean values for Duration for averaged values across three words using rank-order data.

3.12 and 3.13. Results from statistical analyses are found in Table 3.10. As can be seen by comparing Figures 3.8, 3.9 and 3.10 with Figures 3.11, 3.12 and 3.13, respectively, the results from the rank-order data paralled the results from the raw data. The trend towards decreased values over repetitions continued. As with the raw data results, there were significant differences ($p < 0.05$) between repetitions for all three parameters and the relationships were linear. For peak fundamental frequency and duration, the 1st repetition was significantly different (greater) from the 5th and 10th repetitions. The 5th and 10th repetitions were not different. These results were exactly the same as those for the raw data results. For peak amplitude, the trends across repetitions for the rank-order data and the raw data were also similar. However, while the differences between repetitions for the raw data were all significant, for the rank-order data, the 1st repetition was significantly different (greater) from the 10th repetition while the 5th repetition was not different from either. The differences between means for the 1st and 5th repetitions were greater than differences between the 5th and 10th means for peak fundamental frequency and duration. Although differences between means for peak amplitude were similar, the general trend across parameters again suggested that the greatest stress was used on the 1st utterance of the key words.

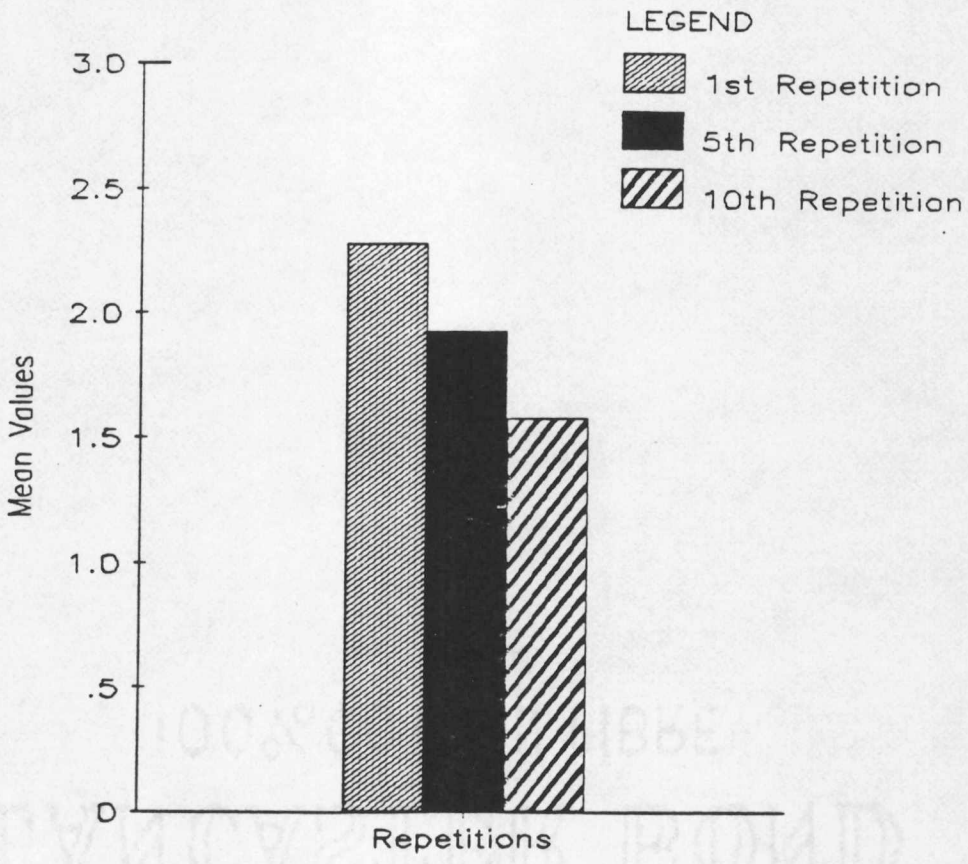


Figure 3.12. Mean values for Peak Amplitude for averaged values across three words using rank-order data.

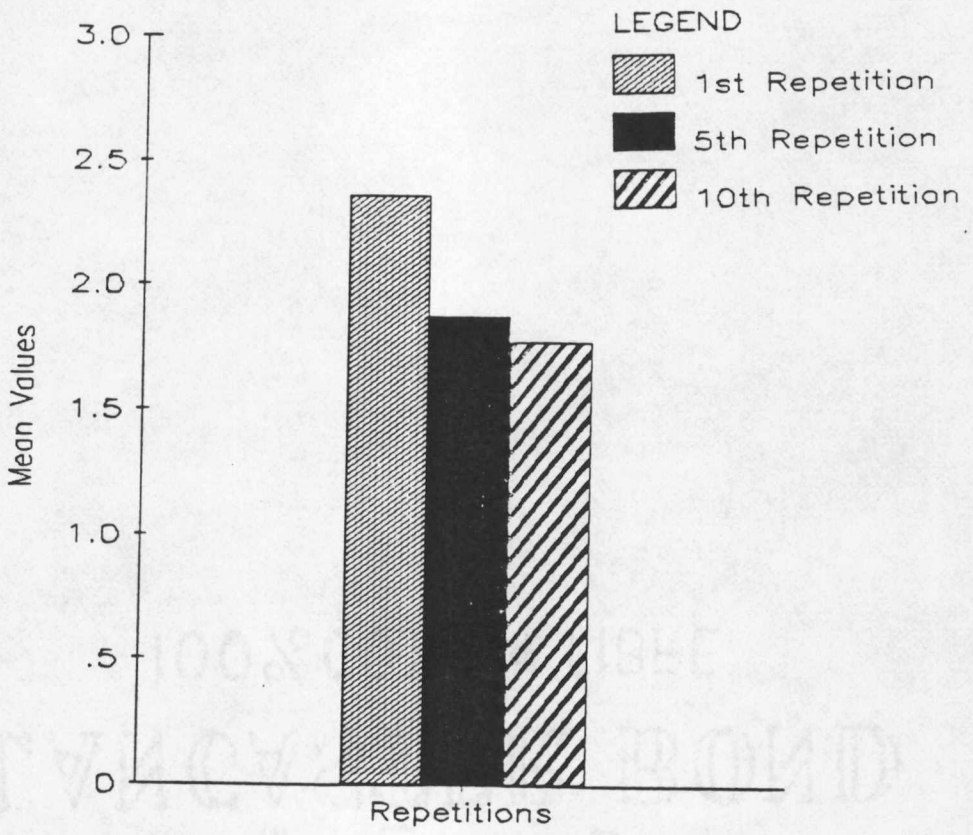


Figure 3.13. Mean values for Peak Fundamental Frequency for values across three words using rank-order data.

Table 3.10. Results from ANOVA procedures for Averaged Vowel Values using rank-order data for Duration, Peak Amplitude and Peak Fundamental Frequency.

Parameter	Analysis	F Value	Probability
Duration	ANOVA	13.70	0.0002*
	Contrast 1-5	10.19	0.0112*
	Contrast 1-10	30.59	0.0004*
	Contrast 5-10	2.62	0.1402
	Linearity	30.59	0.0004*
Peak Amplitude	ANOVA	8.05	0.0032*
	Contrast 1-5	4.25	0.0692
	Contrast 1-10	13.13	0.0055*
	Contrast 5-10	4.85	0.0500*
	Linearity	13.13	0.0055*
Peak Fundamental Frequency	ANOVA	7.23	0.0050*
	Contrast 1-5	12.28	0.0067*
	Contrast 1-10	13.68	0.0049*
	Contrast 5-10	0.29	0.6040
	Linearity	13.66	0.0049*

* significant at p 0.05.

Although not specific to the research questions, one further evaluation was completed. Researchers (Dubno and Levitt 1981; Liberman, 1960; Solie and Arabie, 1979) have stated that syllable stress is produced and perceived as a gestalt of parameters which include duration, peak amplitude and peak fundamental frequency. To evaluate the concept of a gestalt, the averaged rank-order data for the three parameters were averaged together and the analysis was repeated. Means and standard deviations for the averaged rank-order data are found in Table 3.11 and Figure 3.14. Results of the statistical analyses are in Table 3.12. As can be seen graphically, the decrease across repetitions continued. Results from the ANOVA procedures showed the relationship across repetitions was linear ($p < 0.05$) and all repetitions were significantly different ($p < 0.05$) from each other, having a rank ordering highest to lowest of the 1st, 5th and 10th.

With regard to experimental questions one and two which are stated in the introduction, three of the seven parameters had significant differences across repetitions. Those parameters were duration, peak amplitude and peak fundamental frequency. There were no patterns of change across repetitions for the F1 and F2 formant onset and target frequencies that had any consistency across words. For the three parameters exhibiting changes across repetitions, all three had significant linear relationships

Table 3.11. Mean values and standard deviations for the rank-ordered data averaged across parameters and target words.

Mean (Standard Deviation)		
1st Repetition	5th Repetition	10th Repetition
2.395 (0.253)	1.887 (0.217)	1.627 (0.201)

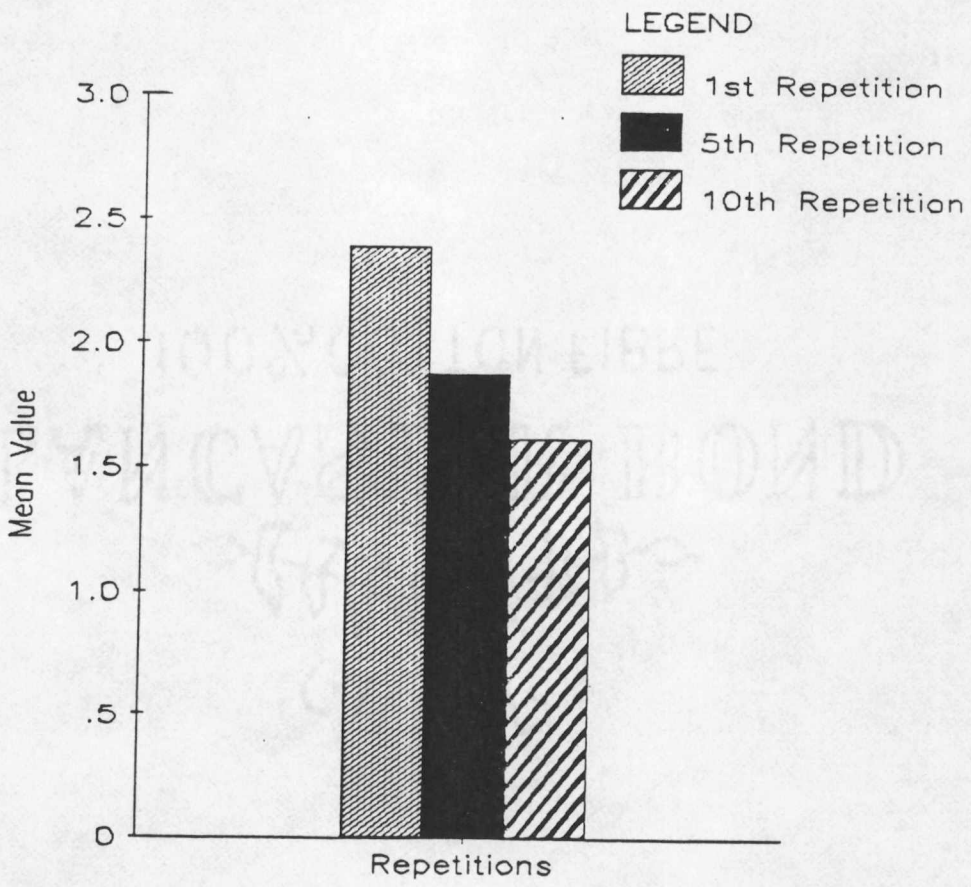


Figure 3.14. Mean values for rank-order data averaged across three parameters and three words.

Table 3.12 Results from ANOVA procedures for rank-order data averaged across parameters and target words.

Analysis	F Value	Probability
ANOVA	20.67	0.0001*
Contrast 1-5	14.28	0.0044*
Contrast 1-10	40.92	0.0001*
Contrast 5-10	5.73	0.0403*
Linearity	40.92	0.0001*

* significant at 0.05.

demonstrating decreasing trends across the repetitions. These findings were the same regardless of the type of data used.

Acoustical Results: Tests of Correlation

Experimental question three, as stated in the introduction, required the determination of any relationships between the measured vowel parameters. There were fifteen comparisons to be made. Pearson Product-Moment Correlations were computed, comparing the 15 parameter pairs for each repetition of each word. These values and their significance levels are reported in Appendix G. All r values which were significant at $p < 0.05$ are shown in Table 3.13. Of the 180 correlation coefficients, 8 (4.4%) were significant. The r values ranged from 0.66 to 0.77, indicating moderate to high correlations (Williams, 1979). Of the 8 significant correlations, 3 were for duration with F2 onset. Of these 3 coefficients, 2 were negative while the other was positive. With respect to experimental question number three, there were no consistent relationships between any parameters, suggesting that parameters were unrelated or independent of each other or that the sample size ($n = 10$) was insufficient to detect any possible relationships between parameters.

Table 3.13. Pearson Product-Moment Correlations obtained from comparisons of Acoustic Parameters which had Significance Levels of $p < 0.05$.

Word	Condition	Parameters	r Value	Significance
peak	1st Repetition	Duration-F2 Onset	-0.683	0.0293
	5th Repetition	Duration-F2 Onset	-0.732	0.0283
thief	1st Repetition	Duration-F2 Target	0.661	0.0370
coupe	5th Repetition	Duration-F1 Onset	0.662	0.0370
		Amplitude-F1 Onset	0.732	0.0159
shoes	1st Repetition	Duration-F2 Onset	0.6481	0.0420
	5th Repetition	Duration-F1 Target	-0.7462	0.0132
	10th Repetition	FO Freq.-F1 Onset	0.7729	0.0087

Perceptual Results

There were no specific experimental questions pertaining to the perceptual results. The results from the original perceptual task requiring the three judges to rank the isolated, triplicate key words for each passage for comparative stress are found in Appendix H. Percentage agreements for the listeners are found in Table 3.14. With an overall percent agreement across the three listeners of 40% ($z = 1.290$, $p < 0.5$) it can be stated that this task was performed at chance levels.

Because the listener agreement was low when rating isolated words, a sample study was completed having two judges listen, independently, to entire passages for the word "coupe" and comparatively rate the 1st, 5th and 10th repetitions for perceived stress. The listeners were given printed passages to assist with this task.

Ratings by the two judges are found in Appendix H. There was 80% ($z = 4.18$, $p < 0.05$) agreement between the two judges indicating that their performance was better than at chance levels. A reponse matrix summed across both listeners for repetition numbers by ratings given is found in Table 3.15. The highest stress ratings were given to the 1st repetition 13 out of a possible 20 times (65%). For the mid stress level, the 10th repetition was selected 50% of the time. The 5th repetition was selected 45% of the

Table 3.14. Percentage agreements between Listeners for judgements of stress across groupings of the three repetitions of each target word.

Listeners	Word	Percentage Agreement
1 and 2	peak	63.3
	thief	63.3
	coupe	86.6
	shoes	56.6
	Average	67.4
1 and 3	peak	63.6
	thief	60.0
	coupe	80.0
	shoes	60.0
	Average	65.8
2 and 3	peak	93.9
	thief	66.0
	coupe	93.3
	shoes	76.6
	Average	82.3
	Overall Average	71.8
1, 2 and 3	peak	40.0
	thief	30.0
	coupe	50.0
	shoes	40.0
	average	40.0

Table 3.15. Response Matrix for Stress Ratings by Repetition Numbers as summed across two listeners.

		Repetition		
		1st	5th	10th
Stress Ratings	High	13	4	3
	Mid	3	7	10
	Low	4	9	7

time for the low stress level. The highest perceived stress was the 1st utterance, which is in agreement with the acoustical measures for the word "coupe" for the parameters of duration, peak amplitude and peak fundamental frequency (See Table 3.16). The perceived stress was similar for the 5th and 10th repetitions which was in agreement with the acoustic measures between these repetitions.

Table 3.16. Mean values for the word "coupe" for the acoustical measures of duration, peak amplitude and peak fundamental frequency.

	Means		
Parameter	1st Repetition	5th Repetition	10th Repetition
Duration (msec)	136.9	134.4	129.4
Peak Amplitude (dB)	3.28	2.84	2.18
Peak Fundamental Frequency (Hz)	141.1	132.6	131.5

CHAPTER IV

DISCUSSION AND CONCLUSIONS

The purpose of this investigation was to measure vowel parameters in repeated words as read in passages and to determine if there were differences within each parameter. Secondary purposes were to examine any trends across repetitions, evaluate any correlations between parameters, and to describe any perceptual differences across repetitions.

The results showed a significant difference among repetitions. The means decreased across repetitions for the parameters of duration, peak amplitude and peak fundamental frequency. These findings were the same for the raw data and the rank-order data. As these trends across repetitions were significant and linear, changes were considered consistent and predictable. Also, the use of rank-order data allowed the combining and averaging of duration, peak amplitude and peak fundamental frequency. The combined results showed an emphasized decreasing trend with significant differences between successive repetitions.

Lehiste (1970) and Linngard (1985) stated that differences in syllable stress were not indicated by differences in vowel amplitude. Because both amplitude and fundamental frequency are regulated by glottal and

repiratory mechanisms, these authors stated that differences in fundamental frequency would provide the stronger stress cue. Results from the perceptual component of this study showed a decrease in stress across repetitions which coincided with the decrease in both amplitude and fundamental frequency. This suggested that both parameters were contributing to a decrease in levels of stress. The contribution of vowel amplitude was different than earlier stated by Lehiste (1970) and Linngard (1985). Differences in methodology (passage readings vs isolated productions) may account for the different results for vowel amplitude.

Vowel duration and fundamental fyrequency decreased across repetitions. This was in agreement with findings by Coker, Umeda and Bowman (1973), and Umeda (1975). Further, because the three parameters (duration, amplitude and fundamental frequency) decreased, the results from this study agreed with the findings of Fry (1955) and Lindblom (1963).

Formant frequency parameters did not change across repetitions. Because of this finding, there was no support in this study that formant frequency positioning changes as a result of word repetition or changes in stress level. The results of this study do not support statements by Gay (1978) that stress levels determine formant frequency positionings, by Lindblom (1963) that formant frequency

positionings are determined by vowel duration or Harris (1978) and Tuller, Harris and Kelso (1982) that formant frequency positionings are duration independent.

Ladefoged, Kameny and Brackenbridge (1976) found that formant frequency positionings remained constant when speakers maintained their speech style. Because comparisons in the present investigation were made across single passages, the speaking style was unchanged, supporting the Ladegoged et al. (1976) finding.

The results of the perceptual study of stress ratings showed that isolated triplet words could not be rated with consistency, regardless of training. In this condition, the judges reported many situations of conflicting stress cues (e.g. one word with higher pitch and another with greater loudness). Judges who rated words for stress using entire passages (perceptual measure) had better agreement and better concurrence with the acoustical measures for duration, amplitude and fundamental frequency. Both showed a decrease in the level of stress. Perceptual ratings of stress therefore required more information than is contained in single words.

Conclusions

Conclusions regarding the experimental questions about acoustical parameter differences between repetitions of words in passages are as follows:

1) There were significant decreases in vowel duration, amplitude and fundamental frequency as repetitions increased. These decreases were observed for both the raw data and the rank-order data.

2) When the rank-order data was averaged across duration, amplitude and fundamental frequency, there was a significant decrease among the repetitions.

3) The four formant frequency parameters (F1 and F2 onset and target frequencies) did not change across repetitions.

4) There were no significant correlations among the seven acoustic parameters.

With regard to the perceptual measures using one of the four key words:

5) There was higher stress for the 1st repetition and similar stress for the 5th and 10th repetitions.

6) Perceptual measures agreed with the acoustical measures for duration, amplitude and fundamental frequency.

Suggestions for Further Study

Several suggestions of changes for future studies were made. In order to determine if there are formant changes over time, the length of the passage should be extended, possibly to lengths of 20 minutes as used by Umeda (1975) and the speakers should be persons who are not experienced readers. These changes should influence the production of target words such that changes across

perceptual vowel categories might occur, due to either declining stress levels or speaker fatigue. Inexperienced speakers might not monitor their speech as closely as the ones used in this study. If changes across vowel categories do occur, the target words should not be screened for consistent vowel identity. Recordings might also be made in less confrontational settings although the quality of recordings needed for analysis might preclude this.

If stress is a suprasegmental feature of speech, the acoustic analysis should include more than the vowel parameters in isolated CVC words. Analysis should include consonant as well as vowel parameters for units up to the size of a phrase or larger. Consonants might be included as some researchers (e.g. Kewley-Port, 1983) believe there are invariant consonant acoustical parameters which, if they exist, might be influenced by changes in syllable stress. Future studies should also involve a more exhaustive perceptual component in order to determine what, if any, perceptual changes occur that might coincide with any acoustical ones. It would also be of benefit to determine if stress is truly produced and perceived as a gestalt of several parameters and if it is, what those parameters are and how they interact.

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APPENDIXES

APPENDIX A

REVIEW OF THE LITERATURE

REVIEW OF THE LITERATURE

Correlates of stress have been studied with essentially two methods; one which involves observation of the positionings and movements of speech related structures (the physiological correlates) and the other which involves analysis of the speech signal parameters (the acoustical correlates). This review will include: physiological aspects and acoustical aspects of stress and also a section on some pilot data.

Physiological Aspects of Stress

Lehiste (1970) defines stress as being an increase in "effort" for stressed as compared to unstressed syllables. Physiological correlates of stress are cited as being reflected in greater activity of the respiratory muscles. Lehiste cites a summary by Ladefoged of Electromyographical (EMG) studies of the respiratory muscles under varying conditions of stress and also changes in subglottal air pressure which thereby result. With connected speech, it was found that bursts of muscle activity correlated fairly well with the principle stresses of utterances. EMG studies, however, were not developed to the extent where it was possible to establish physiological correlates for varying degrees of stress.

Increases in subglottal air pressure can have two main effects; increases in sound intensity and increases in

fundamental frequency. Of the two changes, Lehiste states that intensity changes have little to do with changes in the perception of stress. Since control of vocal fold vibration is held by at least two different physiological mechanisms, it is suggested that there are more mechanisms that control stress than just respiratory effort.

While respiratory effort can account for increases in sound intensity and fundamental frequency (when no tension adjustments are made) for perceptions of stress, there is no physiological cause for the noted increases in the duration of vowels that occur with increased stress. Lehiste states that durational increases are a language-determined phenomenon, especially for Western European languages. She rates the strength of the three parameters or cues to stress as fundamental frequency being the strongest, then duration and lastly intensity. One of Lehiste's conclusions, however, is that the true relative values for these cues to stress can not be stated without integrating cues indicated by changes in "vowel colour." Vowel colour, which is a function of the resonances created by the supraglottal mechanisms, can be defined as the extent to which formant frequencies in vowels reach their acoustic target values. The physiological evidence that Lehiste presents ceases at the glottal level. Fortunately, more recent investigations have reported upon the effects of stress upon supraglottal mechanisms.

Kent and Netsell (1971) stated that the production of stress differences was due to three mechanisms; pulmonary, laryngeal and supraglottal. Studies of the effect upon articulatory gestures were few. They undertook a cineradiographic study in which subjects varied stress on a three word utterance and noun/verb contrasts. Movements for stressed portions of utterances had greater magnitudes; that is, with stress, the jaws opened wider, the lips protruded farther and the tongue body positions appeared to be more displaced in the directions of presumed articulatory targets. Because the magnitudes of the displacements were compensated for by increases in rates of movements, the articulatory overlap between consonant and vowel gestures appeared not to be affected by stress contrasts. The effects of stress contrasts were stated as being subtle due to the requirements of phonetic identity of the sound segments.

Gay et al. (1974) studied displacements and rates of change for the articulators under varying rates of production. They believed that there was more than one mechanism responsible for the control of speech. Using EMG, cineradiography and motion pictures, they studied the productions of syllables comprised of vowels with bilabial consonants. For consonants they found that with increased speaking rates, activity levels and rates of movement increased. This increased articulatory effort when

producing consonants, was stated as being necessary to achieve occlusal targets. Data obtained for tongue movements (e.g. for the vowels) could not be explained similarly. With increased speaking rate, the tongue tended to undershoot its normal position. Accompanying the undershoot was a decrease in muscle activity which the authors stated was related to decreased displacement, not rate of change. They concluded that there were different sets of coordinates (e.g. changes in timing and organization of commands) that operated for different speaking rates and that a general model of speech control based upon a timing ("undershoot") model alone was inadequate.

Keuhn and Moll (1976) studied articulatory velocities using cineradiography. They found that subjects tended to maintain transition times between sounds regardless of changes in rate or stress. Transition velocities were dependent upon consonantal type for VC utterances but not CV. Velocities from vowels to plosive consonants were greater than for vowels to fricatives. They also noted increases in the magnitudes of displacements of the articulators for stressed sounds. Transition times were maintained in these situations by increasing the velocities of the affected articulators. With rate increases, subjects behaved in two manners. Some increased their articulator velocities and maintained positioning while

others maintained articulator velocity and experienced undershoot in positioning. These results suggested again that a speech control model had to include more than just timing constraints.

Harris (1978) conducted an EMG study of the genioglossus muscle in an attempt to further distinguish the effects of stress and rate. Activity levels were always higher for stressed syllables regardless of rate, or stated alternately, when stress was maintained, activity levels did not vary with variations in rate. Harris concluded that the mechanisms for the control of speaking rate and for the duration of vowels were distinct. As such, speakers can use the two mechanisms independently for varying the durations and magnitudes of articulator movements, ultimately resulting in differential allophonic variations.

Tuller, Harris and Kelso (1982) further studied muscle activity changes that occurred under varying speech rates and different stress levels. Their results indicated that with increased stress, peak activity levels increased as did durations of the signals. With increased rates, the peak levels generally remained unchanged while durations decreased. Much variation was noted in activity levels for rate changes. These results were interpretted as reflecting different speaking styles across speakers (e.g. some maintained articulatory targets by increasing

articulator velocities while others experienced undershoot in positioning due to maintained velocities). Tuller et al. (1982) concluded that changes in stress and rate were not due to equivalent motor transformations.

Conclusions from the more recent studies suggest that stress changes can be indicated by changes in muscle activity and in actual articulator positioning. These changes which appear to be independent of speech rate, may be influential in the acoustic structural differences that are noted with stress changes. The problem of relating speech physiology to speech acoustics , however, is that there is more than one way to alter vocal tract cavity shapes such that acoustic requirements are met for varying vowel productions (Borden and Harris, 1984). For example, the traditional concept of the vowel quadrilateral for tongue placement is better reflected by the relative frequencies of vocal tract resonances when the formants are plotted than by actual tongue positioning as revealed by x-rays. Similarly, Fant (as reported by Borden and Harris, 1984) stated that acoustic measurements of speech may be more accurately reflected by vocal tract constrictions than tongue positionings. The conclusion that can be drawn from this is that the different articulator movements which occur due to stress changes, may or may not be reflected in the actual acoustic measures taken. With this caution in

mind, a discussion of the changes in the acoustic signal due to changes in stress is needed.

Acoustical Correlates of Stress

One of the early attempts to define the acoustical correlates of stress was that reported by Fry (1955). In his study, which consisted of two parts, Fry used five nouns/verb contrast pairs (e.g. object vs object). He first measured the "physical" cues of duration and intensity as determined by spectrograms, that 12 speakers used to create stress differences. One hundred listeners then indicated the syllable of stress when listening to synthesized test words developed using the different stress values. Results of the speech production study indicated that vowels were better indicators of stress changes than consonants. Durations were always greater for the stressed vowels. Intensity was also greater for stressed vowels, but to a lesser extent. For the perceptual study, best judgements of stress were made for the syllables which had longer durations and higher intensities. Fry concluded that duration had a stronger influence than intensity for perceptions of stress. Further, when resolving uncertainties about stress, durational differences were more effective than differences in intensity.

Lieberman (1960) reported on an acoustical study which used noun/verb contrasts. He measured fundamental

frequency, relative amplitude, duration and the integral of the amplitude with respect to time for stressed and unstressed syllables. Although relative values of these cues varied from speaker to speaker, Lieberman found that there were "trading effects" whereby the lack of differentiation in one acoustic dimension was offset by changes in another. Conclusions were that fundamental frequency and amplitude were the strongest indicators of stress. Fundamental frequency was a stronger cue than amplitude and amplitude was stronger than both duration and the integral amplitude. A stressed syllable never had both a lower fundamental frequency and lower amplitude as compared to the unstressed syllable. Lieberman concluded that, regardless of the fact that there are more events in the acoustical array than were studied (ie. vowel colour), no absolute statement could be made as to which of the studied cues was more important. Stress judgements were said to be made from "a multiplicity of simple decisions involving several cues."

One of the cues not studied by Lieberman was vowel quality or colour which, again, can be defined as the extent to which formant frequencies in vowels reach their target values. Findings by earlier workers regarding the effects of stress on vowel quality indicated that with an increase in speech rate, all vowels in unstressed syllables approached the common schwa (Stetson, 1951), that as the

degree of stress diminished, vowels appeared to move toward neutral or at least central points on the "vowel diagram" (Tiffany, 1959) and that when comparing the positions of F1 and F2 formants of the vowel in isolation and in natural contexts, both formants are displaced to neutral positions when in context (Shearme and Holmes, 1962).

An often cited study involving vowel quality was that by Lindblom (1963). Lindblom stated that a target was specified by the asymptotic values of the first 2 formant frequencies of a vowel and was independent of consonantal context and duration. Lindblom was interested in developing a dynamic theory of speech production which maintained invariant features of speech sounds while explaining the modifications that ocurred to them in context. One of the features he wished to explain was vowel reduction. Vowel reduction was defined as a characteristic feature of languages with heavy stress, such as English. In English, unstressed vowels are reduced, approaching the schwa quality. The amount of this reduction is related to the degree of stress which is placed on the vowel. Since Lindblom believed that vowel reduction was associated with stress, rate of utterance and contextual influence, his study was based around vowels produced at different rates and in different contexts.

Lindblom's study involved 8 Swedish vowels in plosive contexts. Spectrograms were made of all utterances. He

measured 3 points on each formant; the onset, offset and the point at which the first derivative equalled 0 (that is, the slope of the formant equalled 0). Duration was measured and defined as the interval between plosion of the initial stop and the initiation of the occlusion of the final stop. Results suggested that the targets of F1, F2 and F3 formants were all affected by vowel length decreases, with F2 being the most conspicuous. He proposed that vowel target attainment was a monotonic function of vowel duration.

In Lindblom's discussion, he reiterates that vowel targets were invariant attributes. Although in context, these targets might be realized in a more or less reduced fashion, the intent is always the same. Due to their physical limitations, the articulators can only respond with limited speed, and as timing intervals decrease, the result is coarticulation. With decreased vowel duration, there is less time for articulators to complete their "on" and "off" glide movements within CVC syllables. The result is a failure to reach ideal positions which are reflected in undershoot of the formants relative to a "bull's eye" formant pattern.

Regarding stress differences, Lindblom refutes the argument that vowels produced with less stress are produced with less "effort" (the force of utterance and degree of muscular effort). Modifications noted with unstressed

vowels are due strictly to reduced durations. The "bull's eye" formant patterns can not be reached with stressed vowels at fast rates. Duration is stated as being the main determinant of vowel reduction.

Lindblom's conclusions are supportive of the "undershoot" model of speech production control as opposed to the "extra energy" model. As described by Harris (1978), the "undershoot" model states that the difference between target formant values for vowels of different durations is a consequence of the changes in duration itself. Vowels are specified by the nervous system as a set of signals or commands. These signals result in a specific vocal tract shape unless signals from a subsequent phone arrive at the articulators too soon. Should this occur, the articulatory target is not attained because the movement towards it is deflected towards the second or following target. The "extra energy" model states that extra energy is applied to stressed vowels. This results in longer durations during which the signals to the articulators are larger. These vowels are produced by displacing the vocal tract configuration further than that for unstressed or more neutral vocal tract positions.

The statements made by Lindblom resulted in much word being undertaken to understand the influences which result in vowel reductions. Lindblom himself, refuted these earlier findings about vowel reduction being solely a

function of duration (according to Tuller, Harris and Kelso, 1982). An acoustical study reported by Gay (1978), had differing results from Lindblom's. Gay studied the effects of speaking rate and lexical stress upon acoustic target shifts (or centralization). He wished to determine if stress and rate differences were controlled by the same mechanism. His study involved spectrographic analysis of two utterance types (CVC and CVCVC) using various vowels with labial consonants. He found that both rate and lexical stress affect the acoustic parameters of the vowels. Both affect vowel duration. With rate increases, duration decreases. When stress was maintained, the F2 targets remained unchanged while the F2 onset frequencies shifted towards the target frequencies. Unstressed vowels showed neutralized formant structures. He interpretted these results as indicating that articulator movements were rate independent, initiating at earlier times for increased speaking rates when stress levels were maintained. Utterances spoken at different rates had the same amplitude, fundamental frequency and F1 and F2 formant targets. Unstressed productions spoken at any rate, resulted in decreased amplitude, fundamental frequency and reduced "vowel colour."

Gay (1978) concluded that while speaking rate and lexical stress both affect vowel duration, they have differing affects upon several acoustic parameters and are

probably controlled by different physiological mechanisms. Different mechanisms are needed in order to maintain the information bearing elements of segmental units across different speaking rates. Duration is dependent upon not only stress and rate but also the speech material used, the phonetic context and the word position in a sentence. He concluded that degrees of vowel reduction are related to stress not duration of segments and that stress determines target attainment.

Gay's (1978) acoustical study appears to coincide with the more recent physiological findings (Gay et al., 1974; Keuhn and Moll, 1976; Harris, 1978; Tuller et al., 1982) such that mechanisms that control rate of production are independent of those mechanisms responsible for stress control. It can be said that this is true for the contrived isolated utterances that were studied.

What might follow is an inquiry into the changes in the acoustic parameters that reflect stress changes that occur in more natural utterances. It is possible that the apparent independence of parameters in contrived situations may or may not hold for the more natural. For example, the attainment of formant frequency values with stress, which was stated as being independent of duration for the contrived situation, may or may not be true in the more natural situation.

Several studies have been reported which do show changes in vowel acoustic parameters that occur in more natural contexts. Ladefoged, Kameny and Brackenridge (1976) studied changes in vowel quality that occurred with different styles of speech. They recorded speech in various situations of formality, having a total of 7 styles ranging from conversational to list readings. They measured the frequencies of vowel nuclei (best approximated steady states) for F1 and F2 formants. The formant values for informal styles were scattered about the values for the F1 and F2 for the formal style. No apparent patterns could be otherwise be seen for the scatter. There were no systematic shifts of F1 or F2 that corresponded with shifts of style.

A study by Umeda (1975) showed that when subjects were recorded while reading natural passages of up to 20 minute durations, there was a tendancy for the vowel durations in repeated words to decrease. Coker, Umeda and Browman (1973) reported on stress measures taken on natural samples which they used for the application of rules for the production synthetic speech. They found that while people normally "perceive" up to 3 levels of stress, the perceptual acuity for the correlates of stress (they define as "pitch, intensity , duration, etc".) are sharper and need greater distinction than just 3 levels. Regarding their rules for synthesis, Coker et al. (1973) stated:

> The rules treat stress as a resource for making the listener understand a given word. They therefore attempt to assign word prominence in proportion to the need for the word to be understood, ie., in proportion to an estimate of the information load of the word.
>
> Newly introduced improbable words are difficult to guess from context; therefore they contain much information and are assigned high stress. The first occurrence of an unlikely noun, verb, or other substantive is synthesized almost in "citation form" - pronounced slowly and distinctively. With subsequent repetitions of the word, pitch and other attributes of stress are diminished to those for frequent noun, verbs, and so forth.

Coker et al. (1973) illustrate how stress changes by displaying what they term a "Zipf diagram." The "Zipf diagram" is a plot of word duration against an estimate of information content. It reveals a linear relationship between the variables, such that low frequency of occurrence words have greater durations. They state that their rules for stress have a nine-step scale in which they vary physical attributes for each level. The attributes they employ are elongation (or duration) and main vowel pitch (fundamental frequency). They state that variations in vowel intensity have little effect on varying perceptions of stress.

Although unreferenced by Coker et al. (1973), the use of a "Zipf diagram" refers to the "Principle of Least Effort" as proposed by Zipf (1949). Zipf stated that a speaker will tend to use progressively less energy (or minimizing of effort) as he talks. The initial energy

expended is high as a speaker creates a linkage of understanding with the listener. Establishment of this perceptual linkage frees the speaker to become more lax in his articulatory effort.

While these studies show that there is variation in some of the parameters that occur in repeated words in natural utterances, there has been no study that attempts to relate the role of "vowel colour" with other stress parameters such as duration, fundamental frequency or amplitude. Although information supplied by Coker et al. (1973), Lehiste (1970) and Linngard (1985) suggested that when studying natural utterances, changes in vowel intensity or amplitude have little influence upon stress perceptions, this parameter should be included in an exhaustive study.

It may be possible to assess for possible stress changes as indicated by changes in the above mentioned parameters by following procedures similar to those used by Coker et al. (1973). Those procedures involved the recording of speech signals produced by subjects reading from natural texts. Encorporated into the texts were target words which initially had high semantic prominence (and therefore low predictability). These high prominence words were repeated in the text, having the result of progressively lowering that noted prominence. Reduced prominence resulted in reduced stress as indicated by a

gradually decreasing fundamental frequency and duration. In this present study, the parameters measured were peak fundamental frequency, duration (as proposed by the findings of Coker et al., 1973), the onset and target frequencies of the F1 and F2 formants (as suggested by findings of Gay, 1978) and peak amplitude.

Two pilot studies have been attempted in the assessment of the importance of vowel parameter shifts as indicators of stress changes for words repeated in natural utterances. Their results should be briefly mentioned.

Pilot Studies

Two pilot studies were completed prior to this investigation. In the first study (Dagenais, 1981), six readers recorded two paragraphs, one containing the target word "shoes," the other "cat." Tape recordings were made in an informal situation and the speakers were familiar with the material prior to the recordings. Results showed that there were no apparent patterns of change for vowel durations or fundamental frequencies. Systematic F2 target shifts were noted for the /u/ vowel but not for the / /.

The second pilot study (Dagenais, 1983) was completed as a thesis project. Five subjects read paragraphs containing four nonsense syllabless (/s s/, /sus/, /t t/ and /tut/). There were six paragraphs per word. Readings were recorded under strict conditions with the speakers

previously unfamiliar with the text material. Tape recordings were made in two parts. The initial recordings comprized the majority of the test material. The second recording was made after a ten minute break and involved the reading of one paragraph for each word. Results showed overall vowel duration decreases in the continual readings. No F1 or F2 onset or target frequency patterns existed for individual vowels. Overall F2 target frequencies, however, did shift progressively away from their initial target frequencies. Readings subsequent to the break showed re-establishment of both vowel duration and F2 target frequencies. Fundamental frequencies were unusually high during the first readings and were not re-established. Changes in the fundamental frequency were stated as being indicative of an emotional response to the test situation. Recommendations made were that this type of study be continued with the use of common words as stimuli, read in isolated passages, using subjects who were familiar with the material and not intimidated by the recording situation.

APPENDIX B

READING MATERIALS

READING MATERIALS

PASSAGE NO. 1: PEAK*

It would appear that we are now being required to always function [at our peak]. That is, we are being told to be at our peak for our jobs, at our peak for our physical fitness, at our peak emotionally, mentally and physically. It may be questioned whether it is healthy to always function [at our peak]. Some say that always being at our peak might lead to exhaustion. Others suggest that at our peak we function easiest and thus peak performance is desireable. It is apparent however that our functioning is not always at peak level. Perhaps this is an indication that we are not capable of continual functioning [at our peak]. It may also be possible that different people function best at different levels.

*Note: Each passage has 10 repetitions of the same word. The 1st, 5th and 10th repetitons were analyzed for the experiment. The 10 target words in each passage were not underlined or identified for the speakers.
Phrase which are in parentheses were isolated and recorded on the Language Master cards.

PASSAGE NO. 2: THIEF

It is unfortunate but no matter where one goes, one has to be cautious [of a thief]. Our society has become such that we have to be aware of the potential thief at home, the thief at work and the thief on the street. Very little raises greater feelings of violation than to be the victim [of a thief]. Most people have structured their environments such that they may be protected against the thief. There is still the problem however of the thief that is within these environs, that is the personal acquaintance. This type of person may be not only a thief of material goods but also a thief of ideas and emotions. Thus it becomes imperative that we do guard ourselves against the many ways [of a thief]. To do otherwise could mean the end of all that we value.

PASSAGE NO. 3: COUPE

Of all the different styles of automobiles, one which enjoyed high popularity [was the coupe]. The basic coupe styling was a hard top vehicle with only two doors. The coupe was very popular during the 1930's and 1940's, especially the coupe that was made by Ford. One of the most sporty styles Ford made during that era [was the coupe]. This is not to say that other coupe manufacturers made poorer quality vehicles, but the coupe styles they did make were apparently less appealing. The one exception to this might have been the coupe made by Chevrolet, which was the leading competitor. More recently, the coupe has been rediscovered, only now with hatch doors to make them more useful. It may be unfortunate that they do this, because no vehicle can truly replace the vehicle that [was the coupe]. Further, it may be considered by some as being foolhardy even to attempt it.

PASSAGE NO. 4: SHOES

As our society becomes a more pedestrian one, people are displaying more [interest in shoes]. All one has to do is enter any shopping center to see the many varieties of shoes available. There are shoes for all occassions; formal, casual and of course athletic. Athletic shoes are the ones that have recently changed the most. As a result, it is mostly with athletics that one sees the highest [interest in shoes]. For example, shoes for running are quite different from shoes for aerobics which are quite different from shoes for racketball. It may be that the availability of specialty shoes such as these, is creating greater interests in different sports. Thus we may be becoming healthier, one of the reasons for this being due to an increase in our [interest in shoes]. If this is so, we can only hope that it will continue.

APPENDIX C

PROCEDURES FOR MEASURING VOWEL PARAMETERS

PROCEDURES FOR MEASURING VOWEL PARAMETERS

The following procedures were used to obtain values for the following vowel parameters:

a) duration (ms)

b) peak fundamental frequency (Hz)

c) peak amplitude (dB)

d) onset frequency of F1 formant (Hz)

e) onset frequency of F2 formant (Hz)

f) target frequency of F1 formant (Hz)

g) target frequency of F2 formant (Hz)

All measures were obtained by analyzing spectrograms produced with the Kay 7800 Sonagraph.

Duration: Duration was determined by analyzing wide-band spectrograms. With the exception of the target word "shoes", the words used in this study have unvoiced consonants. As such the duration of the vowels in the words "peak", "thief" and "coupe" could be determined by measuring the elapsed time between the onset and termination of voicing for each vowel. For "shoes", the end of the vowel was determined by the onset of the fricative noise.

Peak Fundamental Frequency: Peak fundamental frequency was determined by using narrow-band spectrograms. The peak of the 10th harmonic frequency was measured using a computer generated overlay and the fundamental frequency was

determined by dividing the measured value by 10.

Peak Amplitude: Peak amplitude was determined by using the amplitude display of the wide-band spectrograms. The peak amplitude of the vowel for the target word with the least amplitude (of the 3 repetitions) was assigned a relative value of 0. The amplitudes for the other two repetitions were measured in relative dB values with the 0 value as a referent. The microphone distance was held constant during all recordings.

Onset and Target Frequencies of F1 and F2 Formants: A two step procedure was required to determine formant frequencies. For the first step, wide-band spectrograms were made of the words. Onsets of formants were determined by the onset of voicing for all words. Target frequencies were determined by locating the asymptotic position of the formants. The times of the onsets and target frequencies were determined from the spectrogram. Then, power-spectra for those times were made. Formant frequencies were measured from the power-spectra using the computer generated overlay. Both the power-spectra and the wide-band spectrogram were used to determine the center frequencies for both F1 and F2 formants.

APPENDIX D

ACOUSTICAL MEASURES

ACOUSTICAL MEASURES

Thief - Duration			Thief - Amplitude			Thief - F1 Onset		
168.25	156.25	162.50	0.546	1.640	1.090	468.75	437.50	390.62
156.25	137.50	162.50	3.281	2.187	3.281	375.00	437.50	406.25
125.00	118,75	118.75	2.734	2.187	0.546	281.25	343.75	375.00
200.00	168.75	168.75	2.734	2.187	0.546	375.00	328.12	390.62
212.50	206.25	181.25	3.282	3.282	2.734	406.25	390.62	406.25
181.25	150.00	150.00	3.282	3.282	1.640	218.75	328.12	343.75
175.00	150.00	168.75	4.375	3.280	2.734	375.00	406.25	422.87
187.50	187.50	156.25	2.734	2.734	1.090	343.75	375.00	375.00
193.75	187.50	187.50	2.187	3.280	2.734	343.75	281.25	312.50
143.75	143.75	150.00	2.187	1.640	1.640	406.25	312.50	437.50

Thief - F2 Onset			Thief - F2 Target		
1968.75	2031.25	1906.25	2296.87	2343.75	2250.00
2000.00	2015.62	2062.50	2312.50	2281.25	2312.50
1906.25	1671.87	1875.00	2000.00	2015.62	2484.37
1968.75	1968.75	2062.50	2468.75	2265.62	2375.00
1687.50	1937.50	1781.25	2312.50	2281.25	2359.37
1640.62	1656.25	1906.25	2250.00	2343.75	2343.75
1500.00	1656.25	1500.00	2093.75	2125.00	2031.25
1906.25	1921.87	1921.87	2281.25	2218.75	2093.75
1906.25	1765.62	1796.87	2281.25	2265.62	2171.87
1750.00	1609.37	1750.00	2234.37	2156.25	2218.75

Thief - F1 Target			Thief - Fundamental		
406.25	281.25	343.75	145.83	138.88	126.73
390.62	375.00	359.38	114.58	111.11	111.11
375.00	250.00	406.25	131.25	125.00	118.75
343.75	375.00	312.50	195.31	173.80	199.20
375.00	343.75	343.75	125.00	125.00	119.14
281.25	281.25	250.00	150.39	148.43	160.15
359.38	234.37	328.12	138.88	142.36	126.73
281.25	281.25	312.50	130.20	145.83	125.00
281.25	312.50	343.75	121.09	117.18	105.46
328.12	343.75	343.75	135.41	114.58	140.62

Coupe - Duration			Coupe - Amplitude			Coupe - F1 Onset		
156.25	150.00	143.70	3.280	3.280	0.000	375.00	406.25	437.50
112.50	112.50	106.25	2.187	2.187	2.187	343.75	343.75	343.75
137.50	131.25	106.25	3.280	2.187	2.187	312.50	312.50	312.50
143.75	143.75	137.50	5.468	5.468	3.280	515.62	500.00	406.25
150.00	118.75	118.75	1.090	0.000	0.000	406.25	218.75	187.50
125.00	137.50	137.50	3.280	2.187	2.187	343.75	359.37	359.37
150.00	131.25	150.00	4.375	3.280	3.280	468.75	437.50	375.00
118.75	137.50	131.25	5.468	5.468	4.375	390.62	375.00	437.50
125.00	143.75	112.50	1.090	2.187	3.280	406.25	421.87	312.50
150.00	137.50	150.00	3.280	2.187	1.090	406.25	406.25	406.25

Coupe - F2 Onset			Coupe - F2 Target		
1515.62	1406.25	1531.25	859.37	1093.75	953.12
1593.75	1468.75	1546.87	1156.25	1218.75	1062.50
1187.50	1281.25	1187.50	843.75	703.12	890.62
1531.25	1484.37	1453.12	687.50	968.75	937.50
1781.25	1812.50	1859.37	1843.75	1593.75	1593.75
1546.87	1500.00	1531.25	937.50	937.50	1031.25
1500.00	1406.25	1312.50	1093.75	781.25	781.25
1562.50	1656.25	1750.00	734.37	1000.00	968.75
1500.00	1421.87	1437.50	812.50	1062.50	968.75
1671.87	1609.37	1750.00	1000.00	1156.25	1187.50

Coupe - F1 Target			Coupe - Fundamental		
421.87	515.62	406.25	125.00	135.41	132.81
375.00	343.75	312.50	125.00	100.00	132.81
375.00	312.50	359.37	163.19	159.72	131.81
437.50	375.00	375.00	223.21	209.82	179.68
343.75	312.50	312.50	131.25	101.56	109.37
250.00	375.00	406.25	159.37	134.37	143.75
343.75	390.62	203.12	135.41	117.18	118.75
281.25	406.25	406.25	130.20	129.46	135.41
218.75	234.37	281.25	118.75	138.39	138.39
375.00	328.12	281.25	100.00	100.00	93.75

Shoes - Duration			Shoes - Amplitude			Shoes - F1 Onset		
275.00	225.00	218.75	5.468	1.090	0.000	312.50	312.50	359.37
237.50	218.75	200.00	3.280	3.380	2.180	343.75	343.75	343.75
200.00	212.50	206.25	3.280	4.375	3.280	312.50	312.50	343.75
262.50	231.25	237.50	4.375	3.280	3.280	453.12	412.87	453.12
275.00	262.55	268.75	2.734	3.280	2.180	359.37	328.12	281.25
256.25	256.25	218.75	3.828	3.280	4.375	312.50	312.50	375.00
287.50	281.25	281.25	2.734	2.734	2.734	312.50	375.00	234.37
256.25	225.00	225.00	2.180	0.000	0.546	343.75	390.62	359.37
300.00	300.00	252.50	2.180	3.280	1.090	250.00	250.00	281.25
231.25	218.75	225.00	2.734	2.734	3.280	343.75	312.50	250.00

Shoes - F2 Onset			Shoes - F2 Target		
2062.50	2078.12	2000.00	1406.25	1578.12	1531.25
1968.75	1984.37	1937.50	1671.87	1656.25	1671.87
1718.75	1750.00	1750.00	1359.37	1562.50	1453.12
2187.50	2250.00	2125.00	1375.00	1500.00	1468.75
2125.00	2078.12	2046.87	1796.87	1968.75	1687.50
1921.87	1906.25	1937.50	1546.87	1468.75	1484.37
1921.87	1859.37	1875.00	1406.25	1390.62	1390.62
1906.25	1984.37	1859.37	1562.50	1578.12	1593.75
2046.87	1968.75	1953.12	1281.25	1437.50	1406.25
1937.50	1812.50	1968.75	1687.50	1718.75	1781.25

Shoes - F1 Target			Shoes - Fundamental		
406.25	421.87	421.87	153.64	145.83	125.00
312.50	359.37	375.00	109.37	106.25	104.68
281.25	437.50	281.25	145.31	146.87	156.25
468.75	437.50	406.25	225.00	204.68	209.37
390.62	250.00	250.00	115.62	126.56	125.00
343.75	343.75	343.75	144.09	158.20	160.15
406.25	359.37	406.25	134.37	118.75	115.62
375.00	406.25	312.50	135.41	125.00	135.41
203.12	265.62	265.62	132.81	121.87	121.09
281.25	375.00	343.75	130.20	130.20	119.79

Peak - Duration			Peak - Amplitude			Peak - F1 Onset		
125.00	125.00	125.00	3.828	2.187	2.187	466.60	300.00	416.60
112.50	106.25	125.00	3.281	2.187	2.187	383.30	233.30	383.30
143.75	137.50	137.50	2.187	3.828	2.187	300.00	416.60	300.00
150.00	137.50	137.50	4.375	0.546	2.187	433.30	400.00	433.30
125.00	112.50	150.00	1.090	1.640	2.730	416.60	333.30	400.00
125.00	118.75	125.00	2.187	2.730	3.281	400.00	383.30	366.60
175.00	150.00	175.00	0.546	0.000	4.375	400.00	266.60	450.00
150.00	125.00	150.00	1.090	0.546	3.281	366.60	400.00	366.60
162.50	125.00	156.25	1.640	0.000	2.187	366.60	416.60	383.30
168.75	150.00	168.75	4.375	2.730	2.187	433.30	500.00	416.60

Peak - F2 Onset			Peak - F2 Target		
2166.60	2233.30	2250.00	2416.60	2466.60	2433.30
2200.00	2216.60	2100.00	2300.00	2266.60	2333.30
1800.00	1733.30	1800.00	2050.00	2000.00	2033.30
2233.30	2133.30	2266.60	2366.60	2366.60	2400.00
2283.30	2200.00	2233.30	2316.60	2250.00	2233.30
2100.00	1950.00	1916.60	2200.00	2216.60	2366.60
1900.00	1500.00	1533.30	2133.30	2033.30	2183.30
2133.30	2066.60	2000.00	2400.00	2233.30	2400.00
1933.30	1933.30	1933.30	2250.00	2200.00	2200.00
1800.00	1866.60	1866.60	2350.00	2250.00	2216.60

Peak - F1 Target			Peak - Fundamental		
333.30	266.60	400.00	138.80	138.80	138.80
333.30	333.30	233.30	106.66	106.66	106.66
250.00	250.00	316.60	131.66	130.00	146.66
333.30	366.60	400.00	200.00	155.50	211.10
200.00	333.30	366.60	133.30	127.70	133.30
266.60	250.00	266.60	111.10	122.20	155.50
233.30	250.00	333.30	122.20	133.30	138.80
300.00	366.60	300.00	122.20	122.20	150.00
433.30	200.00	300.00	122.20	127.70	138.80
250.00	300.00	233.30	116.60	116.60	125.00

APPENDIX E

FORMANT FREQUENCY TABLES

Table E.1. Mean values and standard deviations for F1 Onset, F2 Onset, F1 Target and F2 Target Frequencies in Hertz (Hz) for the three repetitions of the four test words.

Word	Frequency (Standard Deviation)		
	1st Repetition	5th Repetition	10th Repetition
	F1 Onset Frequencies		
Peak	396.6 (46.33)	365.0 (80.68)	391.6 (42.48)
Thief	359.4 (69.48)	364.1 (53.64)	385.9 (36.86)
Coupe	396.4 (60.37)	378.1 (76.82)	357.8 (75.27)
Shoes	334.4 (51.66)	335.9 (48.99)	328.1 (66.29)
	F2 Onset Frequencies		
Peak	2055.0 (180.8)	1983.3 (237.2)	1990.0 (231.9)
Thief	1823.4 (168.6)	1823.4 (167.3)	1856.3 (164.0)
Coupe	1539.1 (151.7)	1504.7 (151.4)	1535.9 (206.6)
Shoes	1979.7 (132.5)	1967.2 (145.9)	1945.3 (103.7)
	F1 Target Frequencies		
Peak	293.3 (67.7)	291.6 (56.7)	315.0 (61.0)
Thief	342.2 (47.4)	307.8 (50.0)	334.4 (40.0)
Coupe	342.2 (71.6)	359.4 (74.0)	334.4 (62.0)
Shoes	346.9 (78.2)	365.6 (66.0)	340.6 (62.0)
	F2 Target Frequencies		
Peak	2278.3 (119.6)	2228.3 (137.2)	2280.0 (127.1)
Thief	2253.1 (127.7)	2229.7 (103.4)	2264.1 (138.5)
Coupe	996.9 (332.7)	1054.7 (246.2)	1037.5 (131.6)
Shoes	1509.4 (169.6)	1585.9 (167.0)	1546.9 (131.6)

Table E.2. Results from ANOVA procedures for F1 Formant Onset Frequencies across three repetitions for the four target words.

Word	Analysis	F Value	Probability
Peak	ANOVA	0.84	0.4475
	Contrast 1-5	1.02	0.3378
	Contrast 1-10	0.34	0.5764
	Contrast 5-10	0.70	0.4241
	Linearity	0.34	0.5764
Thief	ANOVA	1.23	0.3149
	Contrast 1-5	0.05	0.8238
	Contrast 1-10	2.13	0.1785
	Contrast 5-10	2.09	0.1822
	Linearity	2.13	0.1785
Coupe	ANOVA	1.59	0.2308
	Contrast 1-5	0.93	0.3608
	Contrast 1-10	2.01	0.1904
	Contrast 5-10	1.39	0.2685
	Linearity	2.01	0.1904
Shoes	ANOVA	0.13	0.8823
	Contrast 1-5	0.02	0.8794
	Contrast 1-10	0.12	0.7353
	Contrast 5-10	0.16	0.7023
	Linearity	0.12	0.7353

Table E.3. Results from ANOVA procedures for F2 Formant Onset Frequencies across three repetitions for the four target words.

Word	Analysis	F Value	Probability
Peak	ANOVA	2.24	0.1354
	Contrast 1-5	2.78	0.1296
	Contrast 1-10	2.26	0.1674
	Contrast 5-10	0.09	0.7630
	Linearity	2.26	0.1674
Thief	ANOVA	0.41	0.6702
	Contrast 1-5	0.00	1.0000
	Contrast 1-10	0.99	0.3469
	Contrast 5-10	0.51	0.4923
	Linearity	0.99	0.3469
Coupe	ANOVA	0.91	0.4214
	Contrast 1-5	1.85	0.2070
	Contrast 1-10	0.01	0.9255
	Contrast 5-10	1.41	0.2660
	Linearity	0.01	0.9255
Shoes	ANOVA	1.38	0.2758
	Contrast 1-5	0.37	0.5579
	Contrast 1-10	5.76	0.0399
	Contrast 5-10	0.70	0.4248
	Linearity	5.76	0.0399*

*Significant at 0.05.

Table E.4. Results from ANOVA procedures for F1 Formant Target Frequencies across three repetitions for the four target words.

Word	Analysis	F Value	Probabilty
Peak	ANOVA	0.43	0.6595
	Contrast 1-5	0.00	0.9579
	Contrast 1-10	0.57	0.4706
	Contrast 5-10	0.89	0.3703
	Linearity	0.57	0.4706
Thief	ANOVA	1.95	0.1711
	Contrast 1-5	2.76	0.1308
	Contrast 1-10	0.38	0.5505
	Contrast 5-10	1.71	0.2234
	Linearity	0.38	0.5505
Coupe	ANOVA	0.49	0.6215
	Contrast 1-5	0.52	0.4907
	Contrast 1-10	0.07	0.7963
	Contrast 5-10	1.14	0.3122
	Linearity	0.07	0.7963
Shoes	ANOVA	0.70	0.5094
	Contrast 1-5	0.53	0.4861
	Contrast 1-10	0.09	0.7713
	Contrast 5-10	1.79	0.2133
	Linearity	0.09	0.7713

Table E.5. Results from ANOVA procedures for F2 Formant Target Frequencies across three repetitions for the four target words.

Word	Analysis	F Value	Probability
Peak	ANOVA	3.07	0.0712
	Contrast 1-5	6.32	0.0340
	Contrast 1-10	0.00	0.9502
	Contrast 5-10	4.35	0.0667
	Linearity	0.00	0.9502
Thief	ANOVA	0.26	0.7736
	Contrast 1-5	0.82	0.3884
	Contrast 1-10	0.04	0.8555
	Contrast 5-10	0.39	0.5479
	Linearity	0.04	0.8555
Coupe	ANOVA	0.54	0.5928
	Contrast 1-5	0.68	0.4312
	Contrast 1-10	0.43	0.5306
	Contrast 5-10	0.29	0.6039
	Linearity	0.43	0.5306
Shoes	ANOVA	4.05	0.0353*
	Contrast 1-5	7.53	0.0227*
	Contrast 1-10	2.49	0.1488
	Contrast 5-10	1.75	0.2188
	Linearity	2.49	0.1488

*Significant at 0.05.

APPENDIX F

RANK-ORDER DATA

RANK-ORDER DATA

Thief - Duration			Thief - Amplitude			Thief - Fund. Freq.		
3	1	2	1	2	1.5	3	2	1
3	1	2	2.5	1	2.5	3	1.5	1.5
3	1.5	1.5	2.5	2.5	1	3	2	1
3	1.5	1.5	2.5	2.5	1	2	1	3
3	2	1	2	1.5	1	2.5	2.5	1
3	1.5	1.5	2.5	2.5	1	2	1	3
3	1	2	3	1.5	1.5	2	3	1
2.5	2.5	1	2.5	2.5	1	2	3	1
3	1.5	1.5	1	2	1.5	3	2	1
1.5	1.5	3	1.5	1	1	2	1	3

Coupe - Duration			Coupe - Amplitude			Coupe - Fund. Freq.		
3	2	1	2.5	2.5	1	1	3	2
2.5	2.5	1	2	2	2	2	1	3
3	2	1	3	1.5	1.5	3	2	1
2.5	2.5	1	2.5	2.5	1	3	2	1
3	1.5	1.5	3	1.5	1.5	3	1	2
1	2.5	2.5	3	1.5	1.5	3	1	2
2.5	1	2.5	3	1.5	1.5	3	1.5	1.5
1	3	2	2.5	2.5	1	1.5	1.5	3
2	3	1	1	2	3	1	2.5	2.5
1.5	3	1.5	3	2	1	2.5	2.5	1

Shoes - Duration			Shoes - Amplitude			Shoes - Fund. Freq.		
3	2	1	3	2	1	3	2	1
3	2	1	2.5	2.5	1	3	2	1
1	3	2	1.5	1.5	3	1	2	3
3	1	2	3	1.5	1.5	3	1	2
3	1	2	2	3	1	1	2.5	2.5
2.5	2.5	1	1.5	1.5	3	1	2.5	2.5
3	1.5	1.5	2	2	2	3	2	1
3	1.5	1.5	3	1	2	3	1.5	1.5
2.5	2.5	1	2	3	1	3	1.5	1.5
3	1	2	1.5	1.5	3	2.5	2.5	1

APPENDIX G

CORRELATIONAL RESULTS

CORRELATIONAL RESULTS

Note: all results are reported as "r" value
probability

Thief - 1st Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.260	0.276	0.134	-0.149	-0.308	0.661
		0.466	0.440	0.712	0.679	0.385	0.037
Fund.			0.052	-0.011	0.062	-0.040	0.439
Freq.			0.887	0.975	0.864	0.912	0.204
Ampl.				-0.461	-0.617	-0.159	-0.119
				0.179	0.057	0.660	0.742

Thief - 5th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.161	0.439	-0.110	0.389	0.252	0.472
		0.656	0.203	0.760	0.266	0.480	0.168
Fund.			-0.088	-0.048	0.179	-0.101	0.207
Freq.			0.808	0.894	0.620	0.780	0.565
Ampl.				-0.115	-0.293	-0.365	0.084
				0.751	0.410	0.299	0.816

Thief - 10th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur		0.017	0.565	-0.175	-0.281	-0.324	-0.453
		0.961	0.088	0.628	0.431	0.359	0.188
Fund.			-0.130	0.091	0.328	-0.549	0.262
Freq.			0.719	0.801	0.353	0.099	0.463
Ampl.				0.108	-0.127	-0.089	-0.223
				0.765	0.725	0.805	0.535

Peak - 1st Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.103	-0.164	-0.094	-0.684	0.016	-0.196
		0.776	0.651	0.796	0.029	0.965	0.588
Fund.			0.396	0.299	0.338	0.139	0.266
Freq.			0.256	0.401	0.338	0.699	0.457
Ampl.				-0.477	0.068	0.253	0.444
				0.162	0.850	0.479	0.198

Peak - 5th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.373	-0.097	0.442	-0.732	0.193	-0.349
		0.288	0.788	0.200	0.016	0.593	0.323
Fund.			-0.334	0.083	-0.008	0.048	0.237
Freq.			0.344	0.818	0.982	0.894	0.508
Ampl.				0.181	0.061	-0.095	-0.078
				0.617	0.865	0.794	0.828

Peak - 10th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		-0.133	0.425	0.391	-0.597	-0.112	-0.475
		0.712	0.221	0.263	0.068	0.756	0.165
Fund.			-0.002	0.141	0.251	0.579	0.288
Freq.			0.996	0.696	0.484	0.078	0.419
Ampl.				0.270	-0.598	-0.003	-0.012
				0.450	0.067	0.994	0.972

Coupe - 1st Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.034	0.063	0.412	0.109	0.558	0.245
		0.926	0.861	0.236	0.764	0.093	0.495
Fund.			0.499	0.382	-0.337	0.322	-0.315
Freq.			0.142	0.276	0.339	0.363	0.375
Ampl.				0.406	-0.243	0.309	-0.597
				0.244	0.499	0.385	0.068

Coupe - 5th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur		0.542	0.521	0.662	-0.302	0.344	-0.404
		0.106	0.122	0.037	0.396	0.330	0.247
Fund.			0.599	0.526	-0.419	0.091	-0.501
Freq.			0.067	0.118	0.227	0.802	0.139
Ampl.				0.732	-0.204	0.467	-0.519
				0.015	0.572	0.173	0.123

Coupe - 10th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		-0.127	-0.060	0.601	0.171	-0.067	-0.183
		0.725	0.868	0.066	0.637	0.854	0.612
Fund.			0.477	0.269	-0.389	0.503	-0.451
Freq.			0.163	0.451	0.265	0.138	0.190
Ampl.				0.345	-0.334	-0.059	0.619
				0.328	0.345	0.891	0.056

Shoes - 1st Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		0.037	-0.052	-0.202	0.648	0.205	-0.216
		0.919	0.893	0.575	0.042	0.569	0.549
Fund.			0.580	0.627	0.383	0.535	-0.519
Freq.			0.101	0.052	0.273	0.110	0.124
Ampl.				0.304	0.292	0.513	-0.241
				0.426	0.445	0.158	0.532

Shoes - 5th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		-0.214	0.169	-0.327	0.041	-0.746	-0.318
		0.553	0.639	0.355	0.908	0.013	0.370
Fund.			0.165	0.391	0.486	0.488	-0.236
Freq.			0.648	0.263	0.154	0.152	0.511
Ampl.				-0.291	-0.237	-0.239	0.025
				0.414	0.509	0.505	0.944

Shoes - 10th Repetition

	Dur.	Fund.	Ampl.	F1-On.	F2-On.	F1-Ta.	F2-Ta.
Dur.		-0.139	-0.079	-0.529	0.256	-0.165	-0.283
		0.699	0.826	0.115	0.474	0.647	0.427
Fund.			0.435	0.773	0.298	0.144	-0.348
Freq.			0.208	0.008	0.402	0.692	0.323
Ampl.				0.062	-0.027	0.005	0.023
				0.863	0.941	0.988	0.948

APPENDIX H

PERCEPTUAL STRESS RATINGS

PERCEPTUAL STRESS RATINGS

Listener 1.

Word: Coupe

Reader	Most	Mid	Least
1	2	3	1
2	3	1	2
3	2	1	3
4	3	1	2
5	1	3	2
6	1	3	2
7	1	3	2
8	1	3	2
9	2	3	1
10	1	3	2

Word: Peak

Reader	Most	Mid	Least
1	3	2	1
2	3	2	1
3	3	2	1
4	3	1	2
5	1	2	3
6	3	1	2
7	3	1	2
8	3	1	2
9	3	1	2
10	1	3	2

Word: Shoes

Reader	Most	Mid	Least
1	1	2	3
2	1	2	3
3	1	2	3
4	1	2	3
5	2	3	1
6	1	2	3
7	1	3	2
8	2	3	1
9	3	1	2
10	1	3	2

Word: Thief

Reader	Most	Mid	Least
1	3	2	1
2	2	1	3
3	1	2	3
4	1	3	2
5	2	3	1
6	1	2	3
7	1	2	3
8	2	1	3
9	2	1	3
10	2	3	1

Listerner 2.

Word: Peak

Reader	Most	Mid	Least
1	3	2	1
2	3	1	2
3	3	1	2
4	3	1	2
5	2	3	1
6	1	3	2
7	3	2	1
8	1	3	2
9	3	2	1
10	1	2	3

Word: Shoes

Reader	Most	Mid	Least
1	2	1	3
2	2	1	3
3	1	3	2
4	1	3	2
5	3	2	1
6	1	3	2
7	1	2	3
8	1	2	3
9	1	2	3
10	2	3	1

Word: Coupe

Reader	Most	Mid	Least
1	2	3	1
2	2	3	1
3	1	3	2
4	1	3	2
5	1	3	2
6	2	1	3
7	2	1	3
8	3	1	2
9	2	1	3
10	1	3	2

Word: Thief

Reader	Most	Mid	Least
1	2	1	3
2	1	2	3
3	1	2	3
4	2	3	1
5	2	3	1
6	1	3	2
7	1	2	3
8	1	2	3
9	1	2	3
10	3	2	1

Listener 3.

Word: Coupe

Reader	Most	Mid	Least
1	2	3	1
2	3	1	2
3	2	1	3
4	2	1	3
5	1	3	2
6	1	3	2
7	1	3	2
8	1	3	2
9	2	3	1
10	1	3	2

Word: Peak

Reader	Most	Mid	Least
1	3	2	1
2	3	1	2
3	3	2	1
4	3	1	2
5	1	2	3
6	3	1	2
7	3	1	2
8	3	1	2
9	3	1	2
10	1	3	2

Word: Shoes

Reader	Most	Mid	Least
1	1	2	3
2	1	2	3
3	1	2	3
4	1	2	3
5	3	1	2
6	1	2	3
7	1	3	2
8	2	3	1
9	2	1	3
10	1	2	3

Word: Thief

Reader	Most	Mid	Least
1	1	2	3
2	2	3	1
3	2	1	3
4	1	3	2
5	2	3	1
6	1	2	3
7	1	2	3
8	1	2	3
9	2	3	1
10	2	3	1

ADDITIONAL PERCEPTUAL STRESS RATINGS

Listener 1.

Word: Coupe

Reader	Most	Mid	Least
1	1	2	3
2	1	2	3
3	1	2	3
4	1	3	2
5	1	2	3
6	2	3	1
7	1	3	2
8	3	1	2
9	3	1	2
10	2	3	1

Listener 2.

Word: Coupe

Reader	Most	Mid	Least
1	1	2	3
2	1	2	3
3	1	2	3
4	1	3	2
5	1	3	2
6	1	3	2
7	1	3	2
8	3	1	2
9	3	1	2
10	2	3	1

VITA

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