EFFECT OF SPEAKING RATE ON SOME SPECTRAL AND TEMPORAL MEASURES

Register No: 05SLP008
Marly (N.K)

A Dissertation Submitted in Part Fulfillment of
Final year M.Sc (Speech Language Pathology),
University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING
NAIMISHAM CAMPUS, MANASAGANGOTHRI
MYSORE-570006

MAY 2007

"Dedicated to

Jesus Christ

the anchor of my soul

And

My mother-my inspiration

CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of speaking rate on some spectral and temporal measures"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Speech Language Pathology) of the student (Registration No. 05SLP008). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore

May, 2007

Dr. Vijayalakshmi Basavaraj
Director
All India Institute of Speech and Hearing
Naimisham Campus
Manasagangothri
Mysore-570 006.

CERTIFICATE

This is to certify that the dissertation entitled ***"Effect of speaking rate on some spectral and temporal measures"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

Guide

Mysore
May, 2007

Ms. K. Yeshoda
Department of Speech Language Sciences,
All India Institute of Speech and Hearing,
Mysore-570006.

DECLARATION

This is to certify that this dissertation entitled ***"Effect of speaking rate on some spectral and temporal measures"*** is the result of my own study under the guidance of Ms. K.Yeshoda, Lecturer, Department of Speech Language Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other university for the award of any diploma or degree.

Mysore

May, 2007 Register No. 05SLP008

Acknowledgements

Thank you Lord for your faithfulness to me through the ordeals of my life……….

I express my sincere thanks to my guide, Yeshoda ma'm for guiding me throughout this dissertation and helping me complete it successfully.

I extend my heartfelt thanks to Dr. Vijayalalakshmi Basavaraj, Director, AIISH, for permitting me to carry out this study.

I also thank Vasanthalakshmi ma'm for helping me with the statistical work.

I also gratefully acknowledge the work of Mr.Ram Mohan for spending his valuable time and for his effort in helping the dissertation take its present shape.

I also extend my heartfelt thanks to Prof.S.R.Savithri, Reader and Head I/C, Dept of Speech Language Sciences for all the valuable knowledge that she has imparted to me in this subject. Nobody else could have made it more interesting. Attending your classes have been a real pleasure ma'm.

I also thank Papa, Mummy, Sherry chettan and Vava for what they mean to me.I thank God Almighty for blessing me with such a good family.

I thank all my classmates and friends for their support and encouragement.

I thank Mr. Arun. B.T. sir for your timely help and suggestions.

I also thank Anne ma'm for her timely suggestions and encouragement..

Also, extend my sincere thanks to Reshma and Rashmi for helping me with the typing work.

I also extend my thanks to Shiny, Sharon and Lincy for being with me and for helping me in the analysis of the samples.

Special thanks to Sr. Elizabeth for being such a wonderful friend and counsellor. Your suggestions, care, advices and cheerful nature has never failed to help me. Thank you for making my stay in AIISH such a memorable one and for all the help that you've extended to me.

My heartfelt thanks to Johnsi for being a good friend and also for all the help and suggestions you gave.

Thank you so much Maria for your friendship. During times when I really needed some encouragement,you were always there for me. Words are not enough to express just how much our friendship means to me. Just want you to know how blessed I am by your friendhip. May God bless you always.

Also want to thank Raymol for being such a wonderful friend and sister. Thank you so much for understanding me, for all the care and for fighing with me and tolerating all my nonsense. The times we've spent together will always remain as sweet memories.

Also want to thank Meera for being such a good friend. Just remember that wherever we are, will always remember all the joy, laughter and also tears we've shared and also all the pranks we played,the long walks and even longer conversations we've had...You've always made me feel so special with your thoughtfulness and care.

Also thank you so much Jeff for being such a good friend and brother.Will always remember the times we've cared for, helped and irritated each other.

Special thanks to Christopher and Sophia chechi for all the love and affection you've shown me and for always opening your home to me and for all the prayers and comfort in times of need. May God Almighty bless you abundantly and use you to touch more lives.

I also extend my heartfelt thanks to Karuna for all the support and encouragement you've given me during the time of preparing the dissertation and always... love you.

I also express my love and thanks to my juniors Shiji, Maria, Bagchi, Jini, Praveen. You guyz will always remain a part of my pleasant memeories of college life.

Also my sincere thanks to Orin for being such a wonderful friend over the years. Your encouragement and support have never failed to help me. Above all, thank you so much for helping me find my mind ...whenever I lose it. Love you so much dear. You mean so much to me.

Special thanks to Shivappa and co. for all the help with the xeroxs and printing.

I would also like to thank all my subjects who participated in the study for their kind cooperation.

Lastly,want my friends Binda, Juby, Neish, Christina, Neena, Nitta chechi, Priya, Malu, Pradeep, Abishek, Sowmya, Rash, Remu, Indu, Riya, Sherin, Jithin, Arya chechi, Archana didi to know how special they are to me for standing by me throughout my college life and filling it with such sweet memories. Can never forget all the times we've enjoyed together. The assignments we struggled to finish, the pranks we played and the troubles we got into....the outings, the fights and finally making up....but NO THANKS for you guyz..

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Speech is the prime way of communication. It is communicated because it is coded to form words and sentences in a language. The code of speech resides in its sounds. By speech, linguistic information is conveyed in the form of pressure waves traveling from the speaker's mouth to the listener's ears. Thus a deep understanding of speech communication depends on knowing the sound patterns of a language.

The scientific study of speech sounds is called acoustic phonetics. Acoustic phonetics is a branch of linguistics that deals with sound codes of speech and focuses especially on the sound patterns that function in language.

Acoustic phonetics is a part of the general field of speech science, or experimental phonetics, which also includes physiological phonetics. Physiological phonetics describes how the nervous system, muscles, and other organs operate in speech. Acoustic phonetics describes the speech sounds themselves and how they are formed acoustically. Acoustic and physiological phonetics are closely related.

Speech can transmit information to one or more listeners as the result of the combination of both temporal as well as spectral properties, which are used by the recipients for decoding the information. The acoustic speech signal is characterized by short periods of a particular acoustic behavior, typically referred to as phones. They correspond to the acoustic realization of the smallest meaningful contrastive units in the phonology of the language, the phonemes. Phonemes can be coarsely divided into two classes-the vowel type and the consonant type.

Acoustics of speech sounds

Speech sounds are complex in form but they can be represented in simple terms that give us a concise description of any speech sound. Speech consists of a variety of sounds. The variations in acoustic properties of sounds can occur quite rapidly and it is for this reason a spectrogram is desirable form of display and analysis. Sound spectrograph operates on speech wave in order to analyze spectra and make a picture of their spectral changes showing the patterns in time. Many of the most important characteristics of speech (such as formant frequencies, intensity variations) can be seen in the spectrogram as they change in time. Therefore spectrograms are helpful in describing the detailed characteristics of speech thus making them very useful aid in learning acoustic phonetics.

Variations in speaking rate

Part of a speaker's competence lies in his ability to produce an utterance at various rates, ranging from very slow to moderate to very fast. Each speaker varies in their characteristic speaking rates. Speakers also vary their speaking rate, sometimes even within a single utterance. This variation affects the acoustic patterns of speech by restructuring the relationship between the acoustic cues and phonetic categories (Miller, 1981). Speech rate can vary locally within a complete utterance or globally between complete utterances. Speakers tend to slow down towards the end of an utterance producing a local variation in rate. On a global level, utterances can differ in their mean overall rates. Continuous speech vowels are likely to be spoken at a faster rate or tempo than isolation form vowels in isolated words.

Variability in speaking rate results in many-to-many mapping between acoustic properties in speech and the linguistic interpretation in an utterance. In order to recognize the phonetic structure of an utterance, listeners must calibrate their phonetic distinctions against the rate at which the speech was produced.

Effect of speaking rate on temporal parameters

The durational cues change non-linearly with speaking rate (Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967). When a person speaks fast, the overall duration of an utterance decreases. However, the acoustic reduction is not constant. Generally, pauses and steady state segments for vowels and consonants tend to be sacrificed more than transitional or dynamic aspects of the speech signal. At very fast speaking rates, the segments and even unstressed syllables may be deleted (Port, 1982). Speech vowels vary in their temporal properties in particular, in their intrinsic durations with speaking rate (Peterson and Lehiste, 1960).

Rapid rates also tend to be accompanied by undershoots particularly for vowels. It appears that the actual production can deviate from the spatial configuration that occurs for an isolated production of the sound. The rapid rate production takes only about half as long as the slow-rate production (Crystal and House, 1990).

Because changes in speaking rate can affect the base duration of segments, it is important to know how other duration related phenomena such as phrase final lengthening and contrastive emphasis relate to variations in speaking rate. An experiment by Cummins (1999) showed that over a large range of speaking rates, phrase final lengthening and contrastive emphasis combined additively to determine segment durations.

Pickett, Blumstein & Burton (1999) conducted a production and perception experiment to investigate the effect of speaking rate on the singleton/geminate consonant contrast in Italian. Acoustic analyses were performed of labial and dental singleton/geminate consonants produced in words spoken in isolation and in a sentential context and a slow rate of speech. Closure duration was found to discriminate between the two categories of consonants within a given speaking rate.

It has been determined that individual subjects, in fact, often show considerable variation in the extent to which they produce various temporal characteristics in their speech (Crystal and House, 1988 and Smith, 2000). For example, Smith (2000) observed that final-syllable vowel lengthening and postvocalic voiceless (versus voiced) consonant closure lengthening ranged from virtually nonexistent for some native speakers of English to quite extensive for others. It was further noted that at least some of the variation in these temporal patterns among different subjects appeared to relate to the fact that certain speakers 'naturally' tend to talk faster/slower than others (Crystal and House, 1982, 1988; Miller et al., 1984).

Speaking rate substantially affects syllable duration. Indeed, most of the change in a syllable's duration produced by speaking rate is due to a change in the duration of vowel nucleus (Gay, 1978; Kozhevnikova and Chistovich, 1965; Peterson and Lehiste, 1960; Port, 1976). One of the consequences of increased tempo is a decrease in vowel duration since there is less time for the vowel to be produced. The articulators also have less time to attain the vowel target position and as a result, the target may be undershot.

Furthermore, Smith (2000) found that some temporal patterns were greater for speakers who talked faster, while others seemed to be reduced for the same speakers. That is, speech rate appeared to have different consequences for different temporal measures.

In summary, the duration cues change non-linearly with speaking rate and there may also be changes in their spectral patterns. This results in lack of invariance in mapping acoustic cues onto phonetic categories (Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967).

How to measure speech rate?

It is quite normal for users to use the term fast, normal and slow to describe speech rate. In most cases, speech rate is measured by counting phonetic elements per second. Word, syllable, stressed syllable, phoneme are all possible units in the measurement of rate of speech. However, it has been observed that humans do not follow strictly or consistently use these phonetic elements while controlling their speech rate.

Need for the study

Crystal and House (1982, 1988) noted that some temporal patterns may occur only when certain sounds are involved, but not others (e.g. for tense vowels but not lax vowels). Some temporal factors also tend to occur to a greater or lesser extent as a consequence of variations in stress, syllabic patterning, and speaking rate (Weismer and Ingrisano, 1979; Miller et al., 1984, 1986). It is thus also very important to determine the degree to which particular temporal pattern exist in English (and other languages) including the variation they manifest, and if possible, it is of interest to attempt to understand their cause. It is often suggested that these different temporal patterns are a result of either 'universal' aspects of speech production (e.g. perhaps due to biomechanical or other articulatory factors) or that they are learned for language-specific reasons and are thus a result of phonological rules. Hence this study was planned to inquire into the temporal patterns affected by different speech rates.

CHAPTER II

REVIEW OF LITERATURE

When syllable duration is changed, a given transition duration sometimes is judged differently by a listener. For example, a transition duration that is heard as a stop at a slow rate (long syllable duration) it appears that listeners use rate information to make segmental decisions from acoustic patterns. Therefore, segmental (phonetic) decisions are not entirely independent of speaking rate.

An increase in speech rate causes segmental shortening as well as articulatory and acoustic undershoot for vowels (Lindblom, 1936; Gay, 1973) and consonants (Kent and Moll, 1972; Zawadski and Kuehn, 1980 and Farnetani, 1990). There is more overlap in lingual activity between adjacent phonetic segments in fast than slow speech, this has shown to be the case for vowel to consonant effects (Giles and Moll, 1975; Zawadski and Kuehn,1980; Gay, 1981; Engstrand, 1989 and Farnetani, 1990), for consonant-to-consonant effects, cluster /kl/ (Hardcastle, 1985) and for consonant-to-vowel effects (Farnetani and Recasens,1993). A topic which deserves further investigation is the extent to which changes in speech rate affect the relative salience of the anticipatory and carry over effects. An increase in gestural overlap resulting from an increase in speech rate may give rise to an assimilatory process.

In general, studies of tempo effects on co articulation provide less clear-cut support for this view of co articulation as truncation and blending. Other findings suggest that the extent of spatiotemporal blending of gestures is reduced at slower rates of speech. Cutler and Butterfield (1991) noted tighter coupling of CV to VC movements in their study but no intra-gestural modifications particularly in lax vowels at fast tempo.

Linguists have found that variations in rate of speech can affect both perception and production of phones (Miller and Grosjean, 1981; Summerfield, 1981). It has been noted extensively that fast speaking rates tend to coincide with significant phonological reduction, particularly in spontaneous speech (Bernstein et al., 1992). From an information-theoretic perspective, speakers would preserve the most information by concentrating reductions in the least informative words. Many studies showed that changes in rate of speaking affect the dynamics of the speech signal in a complex manner. In general, speech is compressed at higher rates of speech, but some segments (vowels for example) are compressed relatively more than others. Furthermore, the boundaries between phonetic distinctions may change as a function of rate.

So generally speaking one would expect that speech intelligibility is a function of the duration of the speech sample, as the speech sample duration increases its intelligibility increases. Pisoni and Bradlow (1994), in their study didn't find a direct correlation between overall speaking rate and overall intelligibility. However, they found that variability in speaking rate correlates with intelligibility, less variability in speaker rate produces a higher intelligibility.

Gay (1981) studied the relationship between duration and articulation rate over different stretches of speech. It has been confirmed that in spontaneous speech, a measurement of the articulation rate, where pauses are discarded is more appropriate. The highest correlations between the number of linguistic units and articulation time was found to occur on so called inter-pause stretches which occur between two pauses. Since intonation phrases can be longer or shorter than inter-pause stretches, so this result cannot be caused by longer duration of intonation phases. In the same study the correlations of durations and segment rate computed on different speech units were investigated. As was to be expected, it was shown that the best correlation between the number of segments and duration was achieved for the shortest segments, the realized phones, while the longest unit, the intended word only leads to minor correlation because words exhibit a higher variance in duration than phones.

With regard to articulation rate, it is worth nothing that different kinds of phones are affected differently by speaking rate. For example, vowels are affected far more than consonants. A study was conducted in which three different rates of speech was analyzed (Kuehn, 1980). The study consisted of utterances of speakers who were asked to speak slowly, fast or at a normal rate of speech. While the duration of vowels was reduced by 61 % from slow to fast speech, the reduction of unvoiced plosives only amounted to 36% which represents a relative difference of almost 100%.

Differences across the gender for varying rate of speech

In a study, conducted by Bradlow, Kraus and Hayes (2003), the female talker modified her speaking rate and increased the frequency and duration of inter-word pauses to a greater extent than the male talker. The female talker also showed a greater increase in F0 mean for clear speech than the male, and the female talker's overall clear speech vowel space expansion was greater than the males. However, the male talker was more likely than the female talker to avoid reduction processes such as alveolar flapping and unreleased final stop consonants, and the male talker showed a greater increase in pitch range for clear speech than the female talker.

However, de-stressed vowels, even if they are of the same duration and as quickly produced as stressed vowels, are reduced in overall amplitude, fundamental frequency and to some extent, vowel color when the speaking rate in increased. At one speaking rate, the distribution of acoustic properties denote different phonetic categories may overlap substantially; across different speaking rates this overlap becomes much more extreme (Miller and Baer, 1983)

In a more detailed analysis of the shortening of English vowels, it was revealed that intrinsically long vowels are more affected by speech rate than short ones (Miller, 1981) which reduces the absolute difference in duration between long and short vowels in fast speech. Apart from these, phone-specific effects of articulation rate, it has been shown that greater entities than a phone, such as the syllable, also behave differently under variations of the articulation rate.

To sum up, over all speech rate variation is generally attributed to both variations in the articulation rate, which affects the mean segment duration, and pause rate. However, it has been shown that a measure of articulation rate is always influenced by other factors such as the phone identity, the stress pattern or the syllable structure. In order to compensate effect of intrinsic duration, articulation rate is generally measured in syllables per second. The stretch of speech over which the measurement is taken should therefore on the one hand be long enough to reflect the potentially high local variations of articulation rate. The stress pattern remains a variable that is not captured by this measure. For acoustic analysis the articulation rate is the most interesting factor because it affects the duration on the phoneme segments. In the following section, it will be shown how these rather severe durational changes of the phonemic segments in spontaneous speech affect the spectral characteristics of speech.

Many studies have established that vowels before voiced consonants are generally longer in duration than vowels before voiceless consonants (House, 1961; House and Fairbanks, 1953; Peterson and Lehiste, 1960).

Lindblom's (1992) observation of the target-undershoot phenomenon indicates a strong relationship between duration and the acoustic quality of vowels. Therefore target undershoot can also be expected to occur in situations where less speech effort is applied during articulation. This can be the case, for example, in unstressed syllables. Thus one might expect reduction to occur in unstressed syllables rather than in stressed ones. Further more, Lindblom's (1992) study shows that vowel reduction depends solely on both vowel duration and the phonetic context of the vowel. This means that while the duration determines the extent of the reduction the context determines the direction of the formant shift. This would explain Lindblom's observation of an increase variance of short vowels. However if only the mean values of the tokens of a vowel were computed, no effect could be observed. It is a universal phenomenon that rates reduces the distinction of the vowels in informal speech and unstressed syllables. On a global level, it shows that consonants reduce like vowels when the speaking style becomes informal. On a more detailed level, there are differences related to the type of the consonant (Van Son and Louis, 1994) when simply instructed by an experimenter to "speak extra clearly," linguistic researchers have found phonological change toward hyper-clear articulation, restriction in the magnitude of duration-dependent "vowel undershoot," and increased amplitude, pitch, and duration (Moon, 1992; Moon and Lindblom, 1992). Other studies involving similar instructional manipulation have discovered that word boundaries are marked by selective insertion and lengthening of pauses in hyper-clear speech, especially before weak syllables (Cutler and Butterfield, 1991).

Since duration and stress are strongly correlated, it can be argued that it is rather stress than duration that causes vowel reduction, because unstressed syllables are articulated with less effort. However, Lindblom (1992) argues that unstressed syllables are reduced because they are articulated in less time and not due to less articulatory effort. He substantiates this with the results of a small follow up investigation where one speaker had to utter stressed syllables at speech rates from 0.5 to 6 syllables per second. Even though the syllables are stressed, target occurs to same extent as for unstressed syllables. He concluded that there are limitations inherent to the articulation system which are independent of articulatory effort and are based solely on duration.

This point of view, according to which duration is the main factor for vowel reduction, is not unanimously shared in the literature. Vowels can differ substantially in their durations. Among the factors that influence vowel duration are :tense-lax (long-short) feature of the vowel, vowel height, syllable stress, speaking rate, voicing of a preceding or a following consonant, and various syntactic and semantic factors such as utterance position and word familiarity.

F2 transition duration

Moon and Lindblom (1992) showed that speakers are able to talk faster without necessarily reducing the movements of their articulators. In order to obtain speech data that was likely to produce such an effect, they asked their test speakers to talk fast and very clearly. The results showed that while the test speakers did indeed reduce the duration of their segments in order to speak faster, they did not reduce the formant frequencies of their vowels. They achieved this by faster movements of the articulators, which were reflected in steeper slopes of the formant tracts.

Formant transitions have been considered important context-dependent acoustic cues to place of articulation in stop-vowel syllables. According to Port (1982), analysis of Fl, F2 and F3 showed little evidence of context invariant acoustic correlates of place. When vowel context was known, most transition parameters were not reliable acoustic correlates of place except for F2 transition. The results indicated that the information contained in the formant transitions in the natural stop-vowel syllables was not sufficient to distinguish place across all the vowel contexts studied.

Fant (1973) reported in agreement with Ohman's (1966) study, that a constant locus for place could not be obtained from the spectrographic measurements and that F2 and F3 formant transition patterns did not always uniquely specify place of articulation.

For an economic transfer of information in a natural speech situation, a speaker will probably strive to pronounce only the important parts of an utterance clearly and relax his articulation in the less important parts knowing that the listener is capable of filling in fuzzy or missing parts especially semantic and pragmatic knowledge sources can help the listener a great deal in restoring acoustically incomplete messages. But which parts of the utterances are especially important for a proper transfer of the message and which parts are less important?

Although listeners are able to correctly identify reduced vowels in fast speech, they cannot do so without the surrounding context which carries further rate information Klatt (1975). Slow syllables tend to be correctly identified regardless of their surrounding context. This is explained with the assumption that a slow syllable contains enough information about the speech rate. And can therefore not be perceived as fast. Although closely related to the articulation rate, the articulation speed denotes a further variable in speech rate variations. Thus a fast speech rate is achieved by making less and shorter pauses but also by shortening the phones durations. This does not necessarily mean that the articulators have to move faster.

Even more importantly, the temporal changes, which co-occur with speech rate variations, cause severe spectral degradation known as reduction. Reduction is generally described as a shift of the vowel formant frequencies towards the vowel space centre.

Although reduction is strongly correlated with segment duration and articulation rate, there exist several different factors which can cause spectral degradations as well, such as the lack of stress, semantic content or certain emotional states of the speaker. On the other hand, a faster articulation rate is not necessarily accompanied by reduction. If the speaker is aiming at a clear speaking style, he or she can compensate for the shorter segment duration by faster movements of the articulation. This is acoustically reflected in steeper formant movements. Thus there exists no one to one relationship between duration and reduction. It is rather the case that both measures together, duration and the amount of reduction are good predictors of the actual acoustic realizations.

Apart from acoustic reduction of vowels there exists evidence for the acoustic reduction of consonants too. Since formants are not a suitable measure for consonants, the measurement of consonantal reduction is based on different features. One of the most effective measures of consonantal reduction is based on the effects of speech effort. Variations of speech effort are reflected in the tilt of the spectrum.

However, by a more indirect approach where the formant movements of the surrounding vowels are taken into account, even a formant based measure is able to indicate consonant reduction.

It is known that the closure duration of post-vocalic voiced stops is shorter than the closure duration of postvocalic voiceless stops (Lisker, 1957; Port, 1981). Thus the change from a voiced to a voiceless postvocalic stop entails both an increase in closure duration and a decrease in preceding vowel duration.

In normal speech, the closure stage of a plosive tends to be consistent in duration, regardless of the speed of the speech. The duration of the burst also tends to be constant and the suddenness of the onset of energy needs to be maintained (Kuwabara, 1997).

The closure duration was measured from the zero amplitude crossing at the offset of the preceding vowel, to the onset of the burst at the release of the stop. The burst is identified by the abrupt occurrence of high frequency energy following closure (Miller, 1981). The release rate of apicals is expected to be higher than that of laminals (Stevens, 1998) and two possible effects of a faster rate of closure release are a greater likelihood of an abrupt rather than a gradual release, and shorter burst duration.

In particular, one aspect of speech production that any model ultimately must address concerns the temporal variation that occurs within and across speakers. That is, many studies have indicated that English (and other languages) tend to show patterns such as final-syllable vowel lengthening, vowel lengthening before voiced obstruents, etc. [House and Fairbanks, 1953; Peterson and Lehiste, 1960; Lehiste, 1970; Oiler, 1973; Klatt, 1975 and Summers. 1987]. However, it is also known that certain factors can influence the occurrence of these temporal properties of speech in various ways [Crystal and House, 1982, 1988a, b; Miller and Baer, 1983;]. For example, Crystal and House [1982. 1988a, b] has indicated that atleast some patterns often considered 'characteristic' of English may not be as likely to occur when subjects read long passages versus produce citation-form minimal pairs. Possible causes of such patterns are also not known [Davis and Summers, 1989: Smith, 2000], which makes it difficult to attribute them to specific, linguistically based rules. Also adding to the difficulty in determining possible causes of these patterns is the fact that they are not necessarily independent but can, in at least certain instances, interact with one another [Klatt, 1973, 1976; Port, 1979]. In particular, there was a tendency for speakers with slower speaking rates to show greater relative amounts of vowel lengthening preceding voiced stops, whereas the same speakers tended to show lesser amounts of final-syllable vowel lengthening. Commonly considered to be characteristic of English.

Another observation made in the earlier study (Port, 1979) was that although considerable intersubject variability occurred for most temporal parameters that were examined, there was very little difference across subjects when considering the relative durations of low versus high vowels. However, perceptual shifts from VC to CV tend to happen at only fast rates, while changes closure duration are very large throughout the range of rate variation.

As expected, vowel duration was generally longer for the voiced than the voiceless stops (House, 1961; Raphael, 1972) and closure duration was generally longer for the voiceless than the voiced stops (Lisker, 1957). When speech was slowed down, both closure duration and vowel duration increased for both the voiced and voiceless consonants, and by the same percentage as the total sentence duration. Thus, slowing speech seemed to simply stretch the individual segments, keeping constant their relative durations. Increasing the speaking rate, however, had much more complicated effects on the speech signal. First, stop closure duration and vowel duration did decrease for both voiced and voiceless consonants, but the percentage of change was less than the total sentence. Second, the contrast in both closure duration and in vowel duration between the two kinds of stops was weaker at the faster rates of speech.

Aims of the study

1. The primary purpose of the present study was to examine the temporal characteristics as a function of variations in speaking rate.
2. To examine the effects of intentionally manipulated rate of speech on temporal patterns.

CHAPTER III

METHOD

Subjects: Twenty subjects participated in the present study. The subjects constituted of 10 males and 10 females in the age range of 18-30 years.

All the subjects taken for the study were reported to have normal hearing, no history of misarticulations, dysfluencies, dysphonia, craniofacial anomaliesor neurological impairments. All the subjects had Kannada as their mother tongue and were fluent in reading Kannada.

Procedure: Recording was done using the 'Wavepad' software.the subjects were required to talk into a microphone that was place 6cm from the mouth of the speaker.they were given instructions to read as fast as they can for the fast rate of speaking, to read at a normal pace for the normal rate and to read slowly by stressing on each sound clearly for the slow rate of speaking. This was analyzed using the PRAAT software to measure the duration of the various parameters that were considered. A total of 22 words were presented in three sentences that the subjects were required to read. The subjects were instructed to complete reading the sentences three times .i.e. as fast as possible, as slow as possible and at a comfortable speed. Practice trials were given to the subjects who were not considered in the study.

Material: The stimuli consisted of the first three sentences of a standard passage in Kannada-'kriʃna nad̪iju sahjad̪ri. Which contained both voiced and voiceless speech sounds. The middle sentence was considered for extraction of temporal parameters after acoustic analysis.

The sentence that was considered is:

Id̪u huṭuva prade:ʃavu ramanija st̪a:na

Data was collected in an identical fashion for all subjects. An oral reading sample was collected from each participant in a quiet setting.

The parameters considered were

Speaking Fundamental Frequency: The variation in the speaking fundamental frequency was analysed in each of the three speaking conditions, ie fast, slow and normal for each of the subjects by selecting and extracting the frequency value for each speech sample.

Word duration: Word duration was measured by measuring the duration from the onset of the word to the offset.all the five words were considered for the analysis.

Closure duration: The closure duration was measured by measuring the onset of the closure (silent gap) till the onset of voicing. The sounds that were considered are as follows: /ṭ/ in the word /huṭuva/

/t̪/ in the word /st̪a:na/

Burst duration: For burst duration, the sounds that considered are as follows:

/d̪/ in the word /Id̪u/

/ṭ/ in the word /huṭuva/

/p/ in the word /pradeshavu/

/t̪/ in the word /st̪a:na/

F2 Transition duration: For analyzing the transition duration,the syllables considered were /du/ in the word /Idu/

/ṭu/ in the /huṭuva/

/d̪e/ in the word /prad̪e:savu/ and

/st̪a:/ in the word /st̪a:na/

Vowel duration: For vowel duration all the vowels present in each word was considered.

/I/ in /Idu/

/u/ in /Idu/

/u/ in the syllable /hu/

/ṭ/ in the syllable /ṭu/

/v/ in the syllable /vu/

/a/ in the syllable /pra/

/e;/ in the syllable /de:/

/a/ in the syllable /ʃa/

/u/ in the syllable /vu/

/a/ in the syllable /ra/

/a/ in the syllable /ma/

/i/ in the syllable /ni/

/a/ in the syllable /ja/

/a:/ in the syllable /sta:/

/a/ in the syllable /na/

Instruction:

Two trials were given for practice to all subjects and then the sample was recorded for acoustic analysis. In order to simulate speech at the three different rates, the following instructions were given.

Fast rate: Read the first three sentence of this passage as fast as you can.

Slow rate: Read the first three sentences as slow as you can by stressing on every sound.

Normal rate: Read the sentences at the normal speed.

Speech samples were recorded by experimenter to simulate fast>180 WPM (Words per Minute), slow <80 WPM and normal (80 to 180 WPM). For those subjects who were not able to monitor their speech as required by the study, the sample was played as a model.

Data analysis: The recorded samples were analyzed for each of the subject. The parameters considered were:

1. Speaking fundamental frequency (SFF)
2. Word duration
3. F2 transition duration
4. Closure duration
5. Burst duration
6. Vowel duration

All the samples were analyzed using the PRAAT (Version 4.4.04) software.

Each of the sentences spoken at different rates was selected using PRAAT software.

- Mean fundamental frequency was measured for the selected portion using measurement options in PRAAT.

- For word duration, the duration of the word was selected after eliminating silence on either side of the word.

- F2 transition duration was measured as the time between starting of transition to the steady state of the following vowel.

- Closure duration was measured as the portion of silence just before the release of the following vowel.

- For burst duration, the duration of the burst was noted by selecting the portion starting from the starting of the burst to its termination just before the following vowel.

- The vowel duration was noted by selecting the portion from the onset of the vowel till the offset of the same.

CHAPTER IV

RESULTS

The aim of the present study was to quantify the effects of speech rate on the different spectral and temporal measures of speech in Kannada language.

The acoustic parameters that were considered for the study were mean speaking fundamental frequency, word duration, F2 transition duration, closure duration, burst duration and vowel duration.

The above acoustic parameters were extracted in fast, normal and slow speaking tasks.Statistical analysis: Mean, Standard deviation, Repeated measure ANOVA was done to check if there was any significant difference in the above acoustic parameters between fast, slow and normal speech rate. Bonferroni's multiple comparisons test was done to calculate the pairwise differences when significant difference was found.

1) Speaking fundamental frequency (SFF)

Table 1 shows mean standard deviation in SFF for both the genders in all speaking conditions, t-values are also shown in table 1 that are when both genders considered in each condition.

Condition	Gender	Mean	SD	t (18)
Fast	Male	134.55	17.44	9 249 ***
	Female	215.62	21.53	
Slow	Male	128.85	20.45	12.158***
	Female	218.97	11.44	
Normal	Male	126.49	17.41	10.763***
	Female	210.17	17.35	

***Significant difference noticed at 0.001 level.

Table 1: Mean, Standard deviation and t-values for both the genders across speaking conditions.

As can be seen in the table, mean SFF decrease in males from the fast speaking condition to the slow speaking condition and this was further reduced in the normal speaking condition. Whereas for females, there was an increase in the mean SFF from the fast speaking condition to the slow speaking condition.

Independent t-test was administered to check if there was any significant difference in speaking fundamental frequency between male and female for the three speaking conditions, and it was found that there is significant difference between male and female in SFF. The t-values are shown in table 1.

Therefore, repeated measure ANOVA was done to see how each gender behaved on three of the given tasks. Repeated measures of ANOVA revealed that there was significant difference for both male and females across all the three speaking conditions at 0.001 level. The F values of repeated measures of ANOVA are shown in table 2. Bonferroni's multiple pair wise analysis was administered to test which two speaking conditions were significantly different.

Gender	F(2, 18)
Males	4.160*
Females	1.902

* = Significant at 0.05 level

Table 2: Closure duration across gender

Results of Bonferroni's pairwise differences revealed that for males, there is significant difference between fast and normal at 0.05 level. And, no significant difference was observed between fast & slow and slow & normal speaking conditions at 0.05 level.

On the other hand, for females, there is no significant difference between the three conditions at 0.05 level.

2) Word duration

Table 3 shows the mean and standard deviation of word duration for all the five words considered in different speaking conditions. Independent t-test was administered to check for significant differences across the three speaking conditions. Results of repeated measures of ANOVA revealed that there is significant difference between the three speaking conditions (F (2, 38) is significant at 0.001 level.) i.e., fast, slow and normal.

Word	Fast		Normal		Slow		F(2,38)
	Mean	SD	Mean	SD	Mean	SD	
WD1	0.142	0.043	0.272	0.111	0.390	0.167	31.30***
WD2	0.281	0.192	0.484	0.192	0.724	0.317	33.30***
WD3	0.352	0.123	0.671	0.167	0.941	0.311	58.90***
WD4	0.365	0.054	0.557	0.145	0.849	0.387	28.12***
WD5	0.358	0.055	0.531	0.123	0.701	0.238	33.26***

******* Significant difference noticed at 0.001 (2-tailed t-test)

Table 3: Mean and Standard deviation of the word duration across speaking conditions.

Since there was a significant difference across the three conditions, Bonferroni's multiple comparison tests was used to test word duration of which of the two words was significantly different. Bonferroni's test revealed that for all the words there was a significant difference across all the three speaking conditions.

3) Closure duration

Table 4 shows mean and standard deviation of closure duration as well repeated measure ANOVA values.

Closure Duration	Fast		Normal		Slow		F (2,38)
	Mean	SD	Mean	SD	Mean	SD	
CD1	0.081	0.023	0.175	0.160	0.227	0.135	7.3**
CD2	0.056	0.013	0.075	0.022	0.138	0.130	6.40*

** Significant difference observed at 0.01 level
* Significant difference observed at 0.05 level

Table 4: Mean and Standard deviation of closure duration across three speaking conditions.

Independent t-test was administered to see the effect of gender in each parameter and it revealed that there is no significant difference between males and females at at 5% level of significance (p>0.05)

Results of Repeated measures of ANOVA reveal that there is significant difference at 0.01 level for both the items considered.

Since significant difference was noted for some of the values across the three speaking rates, Bonferroni multiple comparison test was done which revealed that there is significant diffrence between the fast and slow speaking conditions at 0.01 level and there was a significant difference between fast & slow and fast & normal speaking conditions at 0.05 level and there was no significant difference for the normal and slow speaking conditions.

4) Burst duration

Results of repeated measures of ANOVA revealed that there is no significant diffrerence across the three speaking conditions for the first item.for the second and the third item, results reveal that there there is a significant difference across the three speaking conditions, ie, fast, normal and slow at 0.01 level and for the fourth item, there is significant difference across the three conditions at 0.01 level.

Burst Duration	Fast		Normal		Slow		F(2,38)
	Mean	SD	Mean	SD	Mean	SD	
BD1	0.0173	0.010	0.03	0.03	0.03	0.018	2.681
BD2	0.0199	0.020	0.02	0.006	0.021	0.008	0.529
BD3	0.028	0.014	0.034	0.013	0.03	0.01	2.397
BD4	0.016	0.008	0.027	0.017	0.027	0.015	4.875*
BD5	0.0281	0.014	0.0327	0.018	0.0391	0.022	2.194

* Significant difference at 0.05 level.

Table 5: Mean and Standard deviation of burst duration

Hence, significant difference was observed for the fourth and fifth token. Patterns showing considerable difference could be attributed to the fact that they require greater learning and might be more sensitive to the linguistic and other factors. So Bonneferroni's multiple comparison tests was administered to find out the difference in this.

5) Transition duration

Table 6 shows mean and standard deviation of transition durations for four tokens.

Transition Duration	Fast		Normal		Slow		F (2,38)
	Mean	SD	Mean	SD	Mean	SD	
TD1	0.063	0.083	0.0568	0.022	0.083	0.032	1.432
TD2	0.0365	0.0109	0.0529	0.030	0.0684	0.039	7.272**
TD3	0.0325	0.009	0.0459	0.0153	0.0552	0.033	7.543**
TD4	0.0313	0.014	0.0549	0.0265	0.073	0.033	17.772***

*** Significant difference at 0.001 level
** Significant difference at 0.01 level

Table 6: Mean and Standard of deviation of F2 transition duration across the three speaking conditions.

All the four tokens seem to follow different trends. Results of repeated measure ANOVA revealed that for the first token there is no significant difference across the three conditions at 0.05 level. For the second token, fast and slow are significantly different at 0.01 level. For the third token, there is significant difference between the fast & slow and fast & normal but no significant difference was observed between the slow and normal speaking conditions at 0.05 level.

And for the fourth token, there is significant difference between the fast and slow and fast and normal speaking conditions but no significant difference was observed between the slow and normal speaking conditions at 0.001 level.

6) Vowel duration

In total 15 tokens were considered for vowel duration measurement. All the vowel durations were seperately analyzed. Table 7 shows mean and standard deviation of vowel duration for each of the 15 vowels.

Repeated measure ANOVA was used to test if there is any significant difference for each of the vowel, and it was revealed that all the vowels showed statistically significant difference. Further, Bonferroni's multiple pairt comparison was done to check in which two speaking conditions the vowel durations were significantly different.

Vowel	Fast		Normal		Slow		F(2,38)
	Mean	SD	Mean	SD	Mean	SD	
V1	0.04	0.02	0.06	0.02	0.10	0.03	42.04**
V2	0.05	0.02	0.09	0.05	0.17	0.06	53.81**
V3	0.05	0.01	0.06	0.02	0.08	0.05	5.28*
V4	0.04	0.01	0.06	0.01	0.11	0.06	16.53**
V5	0.05	0.01	0.07	0.04	0.13	0.07	18.82**
V6	0.05	0.01	0.06	0.02	0.08	0.04	18.71**
V7	0.07	0.01	0.10	0.02	0.15	0.05	33.31**
V8	0.04	0.01	0.08	0.07	0.09	0.03	4.95
V9	0.05	0.02	0.12	0.05	0.18	0.06	47.34***
V10	0.04	0.01	0.06	0.01	0.09	0.05	14.33***
V11	0.03	0.01	0.06	0.01	0.105	0.05	19.40***
V12	0.05	0.01	0.11	0.04	0.19	0.10	33.24***
V13	0.05	0.01	0.07	0.02	0.11	0.06	18.66***
V14	0.08	0.01	0.12	0.04	0.19	0.07	38.26***
V15	0.07	0.03	0.09	0.03	0.14	0.04	28.25***

*** Significant difference at 0.001 level
** Significant difference at 0.01 level.

Table 7: Mean and Standard deviation of vowel duration across the three speaking conditions.

All the tokens were statistically significant different at 0.01 level except for the third i.e. /u/ in 'hu', fifth i.e. /a/ in 'va' and eighth i.e. /a/ in 'sha' which showed certain deviations.

For the third token, no significant difference was observed between fast and normal and normal and slow. However, there was significant difference between the fast and slow speaking conditions at 0.05 level.

For the fifth token, the significant difference was observed at fast and slow and slow and normal at 0.01 levels. However, no significant difference was observed for fast and normal condition.

For the eighth token, only fast and normal conditions showed a significant difference across the conditions at 0.01 level. There was no significant difference between fast and normal and slow and normal at 0.05 level.

CHAPTER V

DISCUSSION

All the parameters that were considered in the present study follow a particular trend across the three speaking rates therefore the results are discussed separately.

The results indicate that there were certain significant differences across the gender for the three speaking conditions only for the mean speaking fundamental frequency and hence the gender aspect was considered only for this particular parameter.

Speaking Fundamental Frequency

According to a study conducted by Bradlow, Kraus and Hayes (2003) on male and female speakers in English, the female speaker was observed to show an increase in mean fundamental frequency in the clear speech condition when compared to the fast speaking condition. And also, the males tend to have a higher pitch variation compared to the female speakers which was similar to the finding by the above authors.

Though studies from literature suggest that vowels are more affected by the rate of speech when compared to consonants, (Lisker, 1957; Port, 1981), some of the tokens in the present study show no significant change in durations with speaking rate of the surrounding speech context.

Vowel Duration

The vowels when preceded by /h/, /v/ & /ʃ/ that did not show significant difference across some conditions were /hu/, /va/ and /ʃa/. According to Miller, 1981, intrinsically long vowels are more affected by speech rate than short ones.

Hence for the third token /hu/, which is an intrinsically long one, though there was a significant difference across the two extremes of slow and fast, there was no significant difference across the fast to normal and normal to slow conditions since these are closer in terms of the rate of production.

Similarly, for the fifth token /va/, no significant difference could be measured across the fast and normal rate of speaking conditions.

The item here is /va/.this syllable was almost deleted and was produced as /a/ in the fast rate of speech condition which is similar to how it is produced in the normal rate of speaking. Only in the slow rate of speech, did the participants produce it as /va/ (the whole syllable). Hence, the deviation seen in this case can be attributed to the fact that they were similarly produced in these two conditions and hence no difference could be observed across the two rates of speaking.

For the eighth token /ʃa/, there was no significant difference across the fast to normal and normal to slow speaking conditions. Only the two extremes of fast to slow showed a significant difference. The syllable in this case was /ʃa/.

Increasing the speaking rate, however, had much more complicated effects on the speech signal. First, stop closure duration and vowel duration did decrease for both voiced and voiceless consonants, but the percentage of change was less than that for the total sentence. Second, the contrast in both closure duration and in vowel duration between the two kinds of stops was weaker at the faster rates of speech. (House, 1961; Raphael, 1972).

Also adding to the difficulty in determining possible causes of these patterns is the fact that they are not necessarily independent but can, in at least certain instances, interact with one another.

Burst Duration

On a global level, it shows that consonants reduce like vowels when the speaking style becomes informal on a more detailed level, there are differences related to the type of the consonant (Van Son and Louis, 1994) and in this study the sounds /du/, did not show any particular difference across the three speaking conditions, whereas all the others showed a significant difference. This could be attributed to the consonant that were present in the study.

Transition duration

For transition duration, the syllables that were considered were /du/, /tu/, /de/ and /sta/ and the transition form the consonant to the following vowel was measured. There was a different pattern followed by all the syllables across the three speaking conditions. This might be due to a number of reasons that have not been considered in this study. These syllables all contained different consonants except for /du/ and /de/, but here again the vowel context was different which could explain the difference in the results.

It was concluded from an investigation by Port (1982) that voiced formant transitions alone do not carry sufficient information. The speed of the movement from consonant to vowel, also, did not seem to change with the change in the rate of speech. These results might also be affected by several additional factors that were not studied. One such complicating factor might be differences in phonetic context. For example, the effect of an increase in speaking rate on transition movements might be different depending on whether the movement is from an alveolar or labial consonant.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Part of a speaker's competence lies in his ability to produce at utterance at various rates, changing from very slow to moderate to very fast. Each speaker varies in their characteristic speaking rates. Speakers also vary their spaking rate, sometimes, even within a single utterance.

The aim of the present study was to quantify the changes that take place in some of the spectral and temporal measures when a person consciously changes the rate of speech. The acoustic parameters that we have considered in our study were:

Word duration

Speaking fundamental frequency

Closure duration

Burst duration

F2 transistion duration

Vowel duration

Twenty normal subjects-ten males and ten females in the age range of 18 - 30 years participated in the study. All the subjects were native speakers of Kannada.

The subjects were instructed to read the first three sentences of a standard passage (kriʃna nadiju) that consisted of both voiced and voicless speech sounds.

Only the speaking fundamental frequency showed a variation across the gender and hence males and females speaking samples were analyses separately.

None of the the other parameters showed a variation across the gender and so the statistical analysis was carried out irrespective of the gender.

In all the parameters that were analysed, there was a significant difference that was observed across the three speaking conditions.

For word duration, there was a significant difference for all the words considered, across the three speaking conditions.

For speaking fundamental frequency, the females showed an increase in the fundamental frequency from fast to normal speaking rates and the males showed an increase in the fundamental frequency from the slow to the fast speaking rates and the normal rate was even more reduced in fundamental frequency.

For the closure duration, there was a significant difference between the fast & slow and fast & normal speaking conditions.

For the burst duration, significant difference was observed for the fourth and fifth tokens and not for the first three tokens

For the transition duration, all the four tokens considered for the study seems to follow different patterns. There was a significant difference in some of the tokens across each of the speaking conditions.

For the vowel duration, there was a significant difference across the speaking conditions for all the vowels that were considered.

Patterns showing considerable difference could be attributed to the fact that they require greater learning and might be more sensitive to the linguistic and other factors.

Implications of the study

- Although number of subjects is less and generalization is difficult, the study results can be applied in forensic voice evaluation. It was observed in the study that some of the acoustic parameters did not vary when the rate of speech was varied deliberately. The unchanged acoustic parameters are helpful in comparing two samples of a person when spoken at different rate of speech.
- The study results can also be applied in speech synthesis in creating speech of different rate. It was observed that some of the acoustic parameters varied with rate of speech. These acoustic parameters can be manipulated to cause an effect of rate of speech.
- Since some temporal factors tend to occur to a greater or lesser extent as a consequence of variations in stress, syllabic patterning and speaking rate, it is

important to know the degree to which particular temporal patterns exist in a particular language, and if possible, it is of interest to attempt to understand their cause.

Future research directions

- Future research can be taken up to test the magnitude of variation in each of the parameter that causes perceptual change in rate of speech. The norms for each of the above acoustic parameter for different rate of speech will be helpful in synthesizing speech at different rate.

REFERENCES

Adams, S.G., Shaiman, S., & Kimelman, M.D. (1997). Velocity profiles of lip protrusion across changes in speaking rate. *Journal of Speech, Language and Hearing Research*, 40(1), 144-158.

Adams, S.G., Weismer, G., & Kent, R. D. (1993). Speaking rate and speech movement volocity profiles, *Journal of Speech &Hearing Research*, 36(1), 41-54.

Blumstein & Stevens, (1979). Acoustic invariance in speech production: evidence from measurements of the spectral characteristics of stop consonants, *Journal of Acoustic Society of America,* 66(4), 1001-1017.

Borden, G. J., & Gay, T. (1978). On the production of low tongue tip /s/: a case report. *Journal of Communication Disorder,* 11(5), 425-431.

Bradlow, A. R., Kraus, N., & Hayes, E. (2003). *Journal of speech, language and Hearing Research,* 46(1), 80-97.

Bruce,L,Smith(2000)Effects of speaking rate on temporal patterns of English, *Phonetica,* 59,232-244

Burnstein, L.E., & Demorest, M.E. (1992), Sources of variability in speech reading sentences, a generalizability analyses. *Journal of Speech and Hearing Research,* 35(4), 876-891.

Byrd D, L. S., Riggs D., & Adams, J. (2005). Interacting effects of syllable and phrase position on consonant articulation. *Journal of Acoustic Society of America,* 118(6), 3860-3873.

Byrd, D. (1992). Preliminary results on speaker dependant variation in the TIMIT database. *Journal of acoustic society of America,* 92(1), 593-596.

Cummins, F. (1999). Some lengthening factors in English speech combine addively at most rates. *Journal of Acoustic Society of America,* 105(1), 476-480.

Chen, F.R. (1980). Acoustic characteristics and intelligibility of clear and conversational speech at the segmental level, Master's thesis, MIT.

Cutler, A and Butterfield, S. (1991). The strong/weak syllable distinction in English. Journal of acoustic Society of America, 97(3), 1893-1904

Delattre, (1956). Tempo of frequency change as a cue for distinguishing classes of speech sounds, *Journal of experimenatl psychology,* 52(2), 127-137.

Edwards, J., Beckman, M. E., & Fletcher, J. (1991). The articulatory kinemaatics of final lenghtning. *Journal of Acoustic Society of America*, 31(4), 206-227

Engstrand, O. (1988). Articulatory correlates of stress and speaking rate in Swedish VCV utterences *Journal of Acoustic Society of America,* 83(5), 1863-1875.

Fant, C.G. (1962). Descriptive analyses of the acoustic aspects of speech. *Logos*, 5, 3-17

Farnetani, E. (1993). Anticipatory consonant to vowel coarticulation in the production of VCV sequences in Italian. *Language and Speech*, 36(2), 213-234

Gay, T. (1968). Effect of speaking rate on diphthong formant movements. *Journal of Acoustic Society of America*, 44(6), 1570-1573.

Gay, T. (1977). Effect of speaking rate on vowel formant transition, *Journal of Acoustic Society of America, 63 (1,) 223-231.*

Gay, T. (1978). Effect of speaking rate on vowel formant movements. *Journal of Acoustic Society of America, 64,326-338*

Gay, T., & Hirose, H. (1973). Effect of speaking rate on labial consonant production: a combined electromyographic high speed motion picture study. *Phonetica,* 27(1), 44-56.

Giles, S. B., & Moll, K. L. (1975). Cinefluorographic study of selected allophones of English */I/. Phonetica,* 31(3), 206-227.

Hardcastle, W.J., Barry, R. A., & Clark, C. J. (1985). Articulatory and voicing characteristics of adult dysarthric and verbal dyspraxic speakers: an instrumental study. *The British Journal of Disorder of Communication,* 20(3), 249-270.

Hertrich, 1., & Ackermann, H. (1997). Articulatory control of phonological vowel length contrasts: kinematic analyses of labial gestures. *Journal of Acoustic Society of America,* 102(1), 523-536.

House, A. S. (1961). On vowel duration in English. *Journal of Acoustic Society of America*, 33,1174-1178.

House, A. S., & Fairbanks, G. (1953). The influence of consonantal environment upon the secondary acoustical characteristics of vowels. *Journal of Acoustic Society of America,23, 105-113.*

House, T. C. A. (1990). Articulation rate and the duration of syllable and stress groups in connected speech. *Journal of Acoustic Society of America*, 88(1), 101-112.

Kent, K. M. (1972). Cinefluorographic analysis of selected lingual consonants. *Journal of Speech and Hearing Research*, 15(3), 453-473.

Kent, R.D., & Moll, K.L. (1993). Speaking rate and speech movement velocity profiles, *Journal of Speech and Hearing Research*, 36(1), 41-54.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: acoustic and perceptual evidence. *Journal of Acoustic Society of America*, 59(5), 1208-1221.

Klatt, D.H., & Klatt, L.C. (1990). Analyses, synthesis, and perception of voice quality variations among male and female talkers. *Journal of Acoustic Society of America*, 87(2), 820-857.

Kuehn, D. P., & Moll, K. L. (1972). Perceptual effects of forward coarticulation. *Journal of Speech and Hearing Research*, 15(3), 654-664.

Kull, P. K., Andruski, J .E., Chistovich, J. A., Chistovich, L. A., Kozhevnikova, E. V., Ryskina ,V. L., Stolyarova, E. I., Sundberg, U., & Lacerda, F. (1997). Cross language analysis of phonetic units in language addressed to infants. *Science*, 277(5326), 684-486.

Kuwabara (1997). Acoustic and perceptual properties of phonemes in continuous speech as a function speaking rate, *Proceedings of Eurospeech*, 97,1003-1006

Lehiste, I. (1970). Some effects of speaking rate on phonetic perception, *Phonetica*, 38(3), 159-180.

Liberman, A. M., Cooper, F. S., Shankweiler, & D. P., Studdert - Kennedy. (1967). Psychological review, 74(6), 431-461.

Lisker, L. (1957). Closure duration and the intervocalic voiced-voiceless distinction in English, *Language*, 33, 42-49.

Lisker, L., & Abramsom, A. S. (1967). Some effects of context as VOT in English stops. *Language and Speech*, 10(1), 1-28.

Lisker, L., & Abramson, A. S. (1970). The voicing dimension: some experiments in comparitive phonetics, in proceedings of the 6th International Congress of Phonetic Sciences Academia, Prague, 563-567.

Lindblom, B., Brownlee, S., Davis,B and Moon,S.J. (1992), Speech transforms, *Speech Communication*, 11(4-5), 357-368.

Miller J.L., Baer T. (1983). Some effects of speaking rate on the production of /b/ and /w/, *Journal of Acoustic Society of America*, 73(5), 1751-1755.

Miller, F. G. (1981). How the components of speaking rate influence perception of phonetic segments. *Journal of Experimental Psychology,* 7(1), 208-215.

Miller, J. A. (1999). Effects of syllable initial voicing and speaking rate on the characteristics on monosyllabic word. *Journal of Acoustic Society of America,* 106(4), 2031-2039.

Miller, J. L. (1981). Some effects of speaking rate on phonetic perception, *Phonetica,* 38,159-180.

Miller, J. L., & Grosjean, F. (1981). How the components of speaking rate influence perception of phonetic segments, *Journal of Experimental Psychology,* 7(1), 208-215.

Ohman, S. E. (1966). Coarticulation in VCV utterances: spectrographic measurements, *Journal of Acoustic Society of America,* 39(1), 151-168

Oller, D. K. (1973). The effect of position in utterence on speech segment duration in Engish, *Journal of Acoustic Society of America,* 54(5), 1235-1247

Peterson, G., & Lehiste, I. (1960).Duration of syllablic nuclei in English, *Journal of Acoustic Society of Ameica,* 32, 693-703

Port, R. F. (1981). Linguistic timing factors in combination, *Journal of Acoustic Society of America,* 69, 262-274.

Port, R. F., & Dalby, J. (1982). Consonant/ vowel ratio as a cue for voicing in engilsh, *Perception and psychophysics,* 32(2), 141-152.

Raphael, L. J. (1972). Preceeding vowel duration as a cue to the perception of the voicing characterisitic of word-final consonants in American English. *Journal of Acoustic Society of Ameica,* 51(4), 1296-1303.

Shaiman, S., Adams, S.G., & Kimelman, M. D. (1997). Velocity profiles of lip protrusion across changes in speaking rate, *Journal of Speech Language and Hearing Research,* 40(1), 144-158.

Stevens, K. N. (1998). *Acoustic Phonetics*. Cambridge, Mass and London: MIT Press

Stevens, K.N and House, A.S. (1961). An acoustical theory of vowel production and some of its implications *Journal of Speech and Hearing Research,* (3)1 303-320.

Summerfield, Q. (1981). Articulatory rate and perceptual constancy in phonetic perception. *Human Perception and Performance,* 7(5), 1074-1095.

Summerfield, Q. (1981). Articulatory rate and perceptual constancy in phonetic perception. *Journal of Experimental Psychology*, 7, 1074-1095 Supplementary report, *Speech Communication*, 10, 335-353.

Van Son, R.J & Pols, L. (1992). Formant movements of Dutch vowels in a text, read at normal and fast rate. *Journal of Acoustic Society of America*, 92(1), 121-127.

Weismer, G, B. J. (2003). Effects of speaking rate on second formant trajectories of selected vocalic nuclei. *Journal of Acoustic Society of America*, 13(6), 3362-3378.

Weismer, G., & Ingrisano, D. (1979). Phrase level timing patterns in English: effects of emphatic stress location and speaking rate. *Journal of Speech and Hearing Research*, 22(3) 516-533

Zawadski, P. A., & Kuehn, D. P. (1980). A cineradiographic study of static and dynamic aspects of American English /r/. *Phonetica*, 37(4), 253-266.

Summerfield, Q. (1981). Articulatory rate and perceptual constancy in phonetic perception. *Journal of Experimental Psychology,* 7, 1074-1095
Supplementary report, *Speech Communication,* 10, 335-353.

Van Son, R.J & Pols, L. (1992). Formant movements of Dutch vowels in a text, read at normal and fast rate. *Journal of Acoustic Society of America, 92(\),* 121-127.

Weismer, G, B. J. (2003). Effects of speaking rate on second formant trajectories of selected vocalic nuclei. *Journal of Acoustic Society of America,* 13(6), 3362-3378.

Weismer, G., & Ingrisano, D. (1979). Phrase level timing patterns in English: effects of emphatic stress location and speaking rate. *Journal of Speech and Hearing Research,* 22(3) 516-533

Zawadski, P. A., & Kuehn, D. P. (1980). A cineradiographic study of static and dynamic aspects of American English /r/. *Phonetica, 37(4),* 253-266.