EFFECT OF CONSONANTS ON VOWEL DURATION IN TAMIL

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CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of consonants in vowel duration in Tamil"*** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Speech-Language Pathology) of the student with Registration No: 09SLP028. 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.

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This is to certify that the dissertation entitled ***"Effect of consonants in vowel duration in Tamil"*** 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.

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DECLARATION

This is to certify that this Master's dissertation entitled ***"Effect of consonants in vowel duration in Tamil"*** is the result of my own study under the guidance of Dr. S. R. Savithri, Director, 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.

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CHAPTER I

INTRODUCTION

Human speech is characterised by articulatory movements with the acoustic speech wave as result. In order to produce speech, the speaker has to precisely time the phonemes. The timing of speech sounds are language specific (Nooteboom, 1972). Phonemes have intrinsic durations. However, their domains are also affected by neighbouring phonemes.

Temporal analysis of speech sounds is useful in understanding the nature and organisation of speech production and phonological theories (Kozhevnikov & Christovich, 1965). It is useful in speech recognition systems and text- to – speech synthesis. Durational data is of immense use in applied research, viz: automatic generation of speech for a reading machine for the blind and the automatic recognition of speech from the acoustic waveform. Thus, it is essential to study temporal characteristics of speech sounds.

Cohen, Schouten and t'Hart (1962), and Kozhevnikov and Christovich (1965) have shown that timing is more important in speech recognition than spectral details, and that prosodic features are most resistant to distortion. Bansal (1966), and Wingfield and Klein (1971) reported that subjects placed more weight on prosodic cues than on segmental details when the two are in conflict. Characterization of sounds with regard to duration is an important factor determining the intelligibility of synthesized speech. For example, in an automatic text-to-speech conversion system for Spanish, van Gerven (1991) included a set of phonetic rules that determine the duration of individual sounds.

Speech sounds can be classified as vowels and consonants. Vowels are speech sounds produced without obstruction in the oral tract. They are continuant, voiced phonemes with no friction (noise) of air against the vocal tract. Therefore, they are simple sounds formed by a continued effusion of the breath, and a certain conformation of the mouth, without any alteration in the position, or any motion of the organs of speech, from the moment the vocal sound commences till it ends (Walker, 1828). They can be described in terms of (a) the relative position of the constriction of tongue in the oral cavity (front, central and back), (b) the relative height of the tongue in the oral cavity (high, mid and low), (c) the relative shape of the lips (spread, rounded and unrounded), (d) the position of the soft palate (nasal and oral), (e) the phonemic length of the vowel (short, long and overlong), (f) the tenseness of the articulators (lax and tense), and (g) the tone.

Consonants are speech sounds produced by interruption of the air puffs/ stream in the vocal tract by articulators. They can be of different place and manner of articulation and voicing. Place of articulation describes where in the vocal tract the phoneme is produced. Depending on the place of articulation, phonemes can be classified as bilabials, dentals, velars etc. The second dimension in the classification is the manner of articulation which refers to the way the phoneme is produced and is a combination of degree of constriction, degree of nasal opening, tongue shape and dynamics (i.e., the way the tongue moves in time). All consonants can be uniquely classified in terms of these functions. Some of the classes of consonants according to the manner of articulation can be plosives/stops, fricatives, affricates, liquids, trills, etc. In most languages, voicing is a binary feature- phonemes can be either voiced or unvoiced.

Vowel systems in different languages differ and there are many factors which affect their duration. Klatt (1976) has classified these factors as (a) extralinguistic factors,

(b) discourse level factors, (c) semantic factors, (d) syntactic factors, (e) phonetic factors, (f) physiological factors. Speakers mood, physical condition and speaking rate are few extralinguistic factors. Other factors like age and gender, which are also extralinguistic seem to influence the vowel duration . In general, younger and elderly seem to have longer vowel duration, slower rate of speech and males are reported to have shorter vowel duration than females. Discourse level factors include phrase/ sentence final vowel lengthening. Semantic factors also play a prominent role in variation of vowel duration. They include emphasis and novelty. Syntactic factors include (a) phrase structure lengthening, and (b) prepausal lengthening. Klatt (1976) in his classical paper also indicated that the syllables before the pause are lengthened when compared to syllables in other positions. Martin (1970) showed that the segments tend to be lengthened in spontaneous speech just prior to major grammatical constituent boundaries. It was also observed at the end of noun phrases and conjoined or embedded clauses. Phonetic factors include intrinsic and context- dependent duration of phonemes.

In general, there are two different methods used to study the effects of consonantal context on the spectral and temporal properties of vowels. One, studies which compare the steady-state formant frequencies and duration of vowels in a "null" or neutral context such as /hVd/ to those produced in the context of various consonants (for e.g. Lindblom, 1963, Stevens & House, 1963, Fourakis, 1991), and another method is to examine the differences in vowels spectrally and temporally in two or more distinctly different contexts, e.g adjacent to bilabial and alveolar stop consonants (for e.g. Livonen & Laukkanen 1993, Schweyer 1996). The actual duration of any vowel will depend on its height, its tonal or accentual properties, its position in the word, the nature of the adjoining segments, word length, grammatical

complexity, speaking rate and psychological and physical state of the individual (Maddieson, 1993).

The intrinsic and context-dependent duration of vowels and consonants have been analysed in several languages (English- House & Fairbanks, 1953; Peterson & Lehiste, 1960; House, 1961; Umeda, 1975; German - Maack, 1953). Research done in Indian languages include Kannada (Rajapurohit, 1982; Savithri, 1986, 1989; Sreedevi, 2007), Malayalam (Velayudhan, 1975; Sasidharan, 1995), Telugu (Nagamma Reddy, 1988, 1989; Krishna, 2009), Hindi (Agrawal, 1988), Tamil (Balasubramanian, 1981; Sangeetha, 2009).

Previous study by Balasubramanian (1981) in Tamil investigated the vowel duration changes with respect to (i) the structure of the syllables in which the vowels occur, (ii) the place of articulation of the post-vocalic consonant, and (iii) the number of syllables in the words in which the vowels occur. The author had focussed on durational variations in different syllable shapes and had not differentially investigated the contextual effects of all the consonants in terms of their place and manner of articulation. Also, only four native speakers of the language were included in that study. Another study in Tamil by Sangeetha (2009) also compared the effects of consonants on vowel duration. But only plosives and few fricatives in 6 vowel contexts were considered and nonsense words were used as the stimuli.

Given the fact that the temporal measurements are useful and that there are limited studies in Tamil[1], there is a need to analyze the vowel duration in detail in Tamil. In

[1]Tamil is a Dravidian language spoken by people in Tamil Nadu, Puducherry and Sri Lanka with about 66 million native speakers (Abraham & Shinu, 2003). It is one of the 22 scheduled languages of India and the first Indian language to be declared as a classical language by the Government of India.

this context, the present study was planned and investigated the effect of consonants on duration of vowels in Tamil. Specifically, the effect of place, manner, voicing of preceding/ following consonants and the position of vowel in the word, and gender differences were examined.

CHAPTER II

REVIEW OF LITERATURE

The review will be focussed on the following:

(1) Importance of vowel duration

(2) Factors affecting vowel duration

(3) Review of relevant literature

(4) Research in Indian languages

(1) Importance of vowel duration

The intrinsic duration of vowel refers to the duration of a segment (vowel) as determined by its phonetic quality (Lehiste, 1970). Vowel duration is the duration from the onset of the vowel to the offset of the vowel. The duration of vowel changes depending on the context, gender, position in the word, and language among others. Vowel duration can be used to signal the stressed syllable (Fry, 1955), mark the word boundaries (Lehiste, 1959), identify the syntactic units (Gaitenberg, 1965), and to distinguish between similar phonetic segments (Denes, 1955; Lisker & Abramson, 1964).

Vowel duration provides information on the linguistic and prosodic aspects of speech. Durational data is of immense use in applied research, viz: automatic generation of speech for a reading machine for the blind and the automatic recognition of speech from the acoustic waveform. This data can be useful in understanding the nature and organisation of speech production and phonological theories (Kozhevnikov & Christovich, 1965). It is useful in speech recognition systems and text- to-speech synthesis.

(2) Factors affecting vowel duration

Effects of post- vocalic consonants

1) Voicing and manner of articulation

Peterson and Lehiste (1960) found effects of about 100 ms for voiced versus unvoiced stops, which is similar to van Santen (1992). This effect is much larger for utterance- penultimate than for utterance- medial position. More effect of post- vocalic consonant than voicing distinction has also been reported. In terms of Manner of production, voiced fricatives produced longer durations than voiced stops, and unvoiced fricatives longer than unvoiced stops (van Santen, 1992). Peterson and Lehiste (1960) reported this effect in voiced fricatives and voiced stops only. Umeda (1975) found a difference between unvoiced fricatives and unvoiced stops. Crystal and House (1988) found effect in terms of voicing characteristic alone and not manner of articulation and only in pre- pausal conditions.

2) Place of articulation

Crystal and House (1988) found that vowels followed by labial or alveolar consonants are longer than vowels followed by velar consonants. But Luce and Luce (1985) reported of only slight difference yielded by labial stops and velar stops. van Santen (1992) on re- examining the data by Crystal and House (1988) indicated that back vowels were unaffected by place of articulation while front vowels were shortened by velars.

Effect of consonant that follows post- vocalic consonant:

Chen (1970), and Crystal and House (1988) reported that the effects of the post- vocalic consonant on vowel duration may persist even when a nasal or liquid separates the two. van Santen (1992) indicated that nasal or liquid did not merely reduce the magnitude of the effects of the final consonant, but reduced the nature of its effect to that of voicing.

Effects of the pre- vocalic consonant

i) Effects of the preceding consonant

Maack (1953) when investigating vowel duration in German, found that the German vowels were proportionally longer, the closer their point of articulation was to that of the preceding consonant. That is, the prevocalic consonants had an effect on vowels that was opposite to the one observed for postvocalic consonants. Peterson and Lehiste (1960) reported a tendency of vowels preceded by fricatives to be shorter than vowels preceded by other consonants. Also, depending on where the aspiration is added, the effect varied. That is, if the aspiration is included in vowel, this would make vowel durations longer after unvoiced stops than after the consonants. If included in the consonant, voiced stops would have produced the longest vowel durations. But when comparing the influence of initial consonant upon the durations of syllable nuclei, the effect was negligible for American English.

For Danish, Fischer- Jorgensen (1964) also found longer durations for vowels after voiced stops than for vowels after unvoiced stops, as did

Crystal and House (1988). She noted that in comparison to vowel duration after /h/, vowels were significantly longer after initial voiced and shorter after initial unvoiced stop consonants. Also, the initial consonants affected vowel duration in the same direction as postvocalic consonants: with vowel duration being shorter after bilabial than after alveolar and velar stop consonants.

Crystal and House (1988) also added up that both unvoiced and voiced stops produce longer vowel duration than any other consonants, including fricatives. In all cases, the effects were much smaller than the effects of the post- vocalic consonant.

However, Suomi (1976) reported of no effect of the prevocalic consonants on vowel duration except for /g/. Strange, Edman, and Jenkins (1979) reported of similar findings. They found that the prevocalic bilabial stop consonants in CV syllables did not shorten vowel durations. The lax vowels in the /pV/ context were even longer than in isolation, although the tense vowels in /pV/ and the tense and lax vowels in /bV/ syllables were slightly shorter than in isolation leading to a consensus that the effect of prevocalic consonant is small on vowel duration. Inconsistent results were obtained by Port and Rotunno (1979), who studied the production of the words *pin, tin, kin, pipped, tipped,* and *kipped* by eight American English speakers. They found that vowel duration was shortened by prevocalic /p/ as compared to vowels preceded by /t/ or /k/. However, this effect was not observed in a further experiment.

ii) Effects of the preceding consonant cluster

Results of experiment by van Santen (1992) showed a reduction in vowel duration by 10 – 20 ms when a vowel is preceded in the same word by a stop- liquid cluster or a fricative- stop- liquid cluster.

Syllable position

a) Word- based syllable position factors: Nooteboom (1972), Klatt (1973), and Port (1981) have researched on syllable position factor and have reported that duration of stressed vowels in word- initial syllables decreases as the number of syllables increases. Also, duration of stressed vowels in word- final syllables is longer than in word- medial syllables (Nooteboom, 1972; Oller, 1973). In Italian, effects were found of the number of syllables that follow the vowel in the word, but not of the number of preceding syllables (Farnetani & Kori, 1986) in slowly read phrase- final words in carrier phrases. Umeda (1975) found no difference in the duration of stressed vowels in word- final syllables versus non- word- final syllables in rapid connected speech. Harris and Umeda (1974) found that the effect of the number of syllables on stressed vowels in word- initial syllables is present but it is affected with the speaking mode and is totally absent in connected speech.

b) Stress- interval based syllable position factors: Kovacs (2002) in his study on tendencies and rules in production of vowel duration in

Hungarian vowels reported that voicing of the postvocalic stops in sentence- medial position is not consistent, only the pre-pausal position gives rise to the negative correlation between vowel and consonant durations. Also, evidence of syllable- timed character was observed with moderate but significant shortening of vowels in the stressed syllables, and both singleton and geminate post- vocalic consonant and CVC and CVCC syllable structure inducing consistent lengthening.

Effects of symmetric consonant environment

House and Fairbanks (1953) recorded symmetrical CVC syllables spoken by an American English speaker. The consonants taken were plosives, fricatives and nasals. The authors found that vowels were shorter in velar contexts than vowels in bilabial environments. Thus vowel duration was affected by place of articulation in the following order: velar < bilabial < alveolar. But the data is to be interpreted with caution because the velar context included only voiced and unvoiced stop consonants, whereas the bilabial and alveolar contexts included voiced fricatives and plosives also.

This brief look into the literature, shows us that the factors most responsible for the variations in vowel duration are the place, manner, and voicing of the consonantal context in which it occurs. The following section will give a more detailed description of these effects.

(3) Review of literature

Effect of Place of articulation

House and Fairbanks (1953) recorded an American English speaker who produced American English vowels in symmetrical CVC syllables. The consonants were plosives, fricatives and nasals. They found that vowels in velar contexts were shorter than vowels in alveolar contexts. Thus Vowel duration was affected by the place of articulation in the following order: Velar < Bilabial < Alveolar. Maack (1953) measured the duration of German vowels and reported that the place of articulation of a given stop consonant affects the duration of the preceding vowel. The vowel duration was shortest before bilabial and longest before velar stop consonants. However, if front and back vowels were separated, then front vowels were longer before labials and velars than before alveolars and back vowels were longest before labials and shortest before velars. Maack had concluded that the further away the place of articulation of a vowel from that of the following consonant, the longer the vowel.

Maack (1953) had described CV segmental durations and reported that a trend 'V+ velar > V+ dental > V+ labial'. A similar description was made by Lehiste (1976), who said that vocalic duration increases as the point of articulation of the postvocalic consonant shifts farther back in the mouth. But in connected speech, the reverse order was found in the Crystal and House study (1988).

In a crosslinguistic study with English and Spanish, Zimmerman and Sapon (1958) compared the effects of consonantal context on vowel duration. The pattern of results was different in the two languages chosen. In Spanish when two speakers and 90 words were taken, increase in vowel duration was seen when

point of articulation of the postvocalic consonant was back, i.e. Spanish vowels were shortest before bilabial and longest before velar stop consonants. For English speakers (two speakers and 38 words), velar context produced the shorted vowel duration and alveolar stops the longest. Hence the authors had concluded that the place of articulation of stop consonants affected vowel duration differently in English and Spanish.

Peterson and Lehiste (1960) ordered vowel length according to the place of articulation and voicing characteristic, with increasing vowel duration progressively with unvoiced stops, unvoiced fricatives, nasals, voiced stops and voiced fricatives in the preceding context. In specific, for voiced plosives, the order of the duration of the short vowels was velar > alveolar > bilabial and for long vowels, alveolar > velar> bilabial. Thus, in American English, vowels before the bilabial stop consonants were short whereas vowel duration before alveolar and velar stops depended on the inherent length of the vowel and the voicing characteristics of the postvocalic consonant. But in the Crystal and House study (1988), progressive lengthening of short vowels before /t/, /s/, /d/, and /z/ was not observed.

Fischer- Jorgenson (1964) discussed the lengthening/ shortening of back vowels before labials and dentals and lengthening/shortening of front vowels before velars. In Danish, she investigated /i:, I, u:, u, y:, y/ in CVC or CVCə syllables. All the consonants were stops in different places of articulation. In general the vowels were shorter before /b/ than before /d/ and /g/. Front vowels were longest before bilabials and velar than before alveolar stop consonants. Back vowels were shortest before /b/ and longest before /d/. She had concluded that the duration of a

vowel depends on the extent of the movement of the speech organs required to come from the vowel position to the position of the following consonant. The greater the movement, the longer the vowel. But slightly different results were reported in German itself. Vowel duration before /t/ was longer than before /p/ and /k/, and the back vowels were shorter than front vowels before /p/. But such a pattern was not observed preceding /k/. Therefore, it was concluded that due to temporal constraints for the articulatory gestures from vowel to consonant, vowels before stop consonant with a peripheral place of articulation (i.e. bilabial and velar) were shorter than before stop consonants with a central place of articulation (i.e. alveolar).

Lehiste (1970) reported that, English tense vowels and diphthongs are usually longer than their corresponding lax vowels as observed between /i/ and /I/. Also, differences in duration are reported as a function of place of articulation.

Klatt (1976) opines that (a) bilabial stops are typically slightly longer in duration than alveolars and velars.

Suomi (1976) studied vowel duration in five British English speakers who produced eleven British English vowels in /CVC/ stop consonant syllables in a sentence context. On examining the data, it was found out that vowels were longest before alveolar, shorter after velar and shortest before bilabial stop consonants. The production of British English and Dutch vowels in CVC syllables was studied by Elsendoorn (1984). The results of British English diverged from Suomi's findings in the fact that although both studies found vowel duration to be longest before alveolar consonants, they disagreed on which place of articulation shortened preceding vowels most, velars shortened vowels more than bilabials. In

Dutch, the trend observed was that vowels were shortest when followed by a velar consonant and longest when followed by a dental consonant.

As reported by Zue (1976), there is a complex pattern in terms of place of articulation effects. He noticed a tendency for alveolars to be slightly shorter than labial and velar stops. This he attributed to the fact that the release of these categories have a different pattern. The averages in general increased as the point of articulation moved from the lips to the velum. Also, the duration of vowel changes with the duration of the consonant associated with it.

O' Shaughnessy (1981) reported that in word- initial position in French, the consonants which are longer are the fricatives, consonants with back- place of articulation, and unvoiced consonants. Hence, the vowels associated would be shorter. Krause (1982) reported that, intrinsic vowel duration increased as the place of articulation of the post vocalic consonant moved posteriorly.

Luce and Luce (1985) also reported that vowels preceding bilabials were longer than vowels preceding velars or alveolars. Here the vowels considered were /i:, I, a:/ in the context of /p, b, t, d, k, g / in CVC syllables produced in a carrier phrase. Although this result was in accordance with the results of some studies on American English vowels (e.g. House & Fairbanks 1953, Zimmermann & Sapon 1958), it does not agree with Peterson and Lehiste (1960).

Crystal and House (1988) examined segmental duration in English in connected speech. Six talkers read two scripts of 300 words each in two different rate of speech- slow and fast. The authors also report of tendency of velars to be more complete than other places of articulation. Hence, vowels were longer before

labial than before alveolar or velar consonants. When vowels were stressed, they were shorter before velar than before labial and alveolar consonants. These results agree with Luce and Luce's (1985) findings, although they are not in consensus with the general expectation that vocalic duration before consonants increased as the place of articulation moved from front to back, that is, from labial to a velar place of articulation (Maack 1953, Peterson & Lehiste 1960). The trend observed with front and back vowels were similar to that of what Fischer- Jorgensen (1964) observed, with back vowels shorter than front vowels before velars and longer than front vowels before labials and dentals. Crystal and House (1988) suggested that this is the alveolar- centred than a front – back effect.

The reason why vowels behave in certain way could be dependent on the motoric constraints and linguistic attributes of the language. The greater the extent of movement required to produce the following consonant, the longer may be the vowel duration. For example, vowels are shorter before /b/ than before /g/, as there is no time delay in moving the articulator (i.e. the tongue) from vowel target to consonant (Vowel + bilabial). It is also reported that back of the tongue is not mobile as the tip of the tongue which further results in durational variations.

Effect of Manner of articulation

Halle and Stevens (1967) in their study in English, reported that vowels before nasals had the shortened duration. Hogan and Rozsypal (1980) observed that the vowel duration differences is more for final fricatives than for stops or clusters.

O' Shaughnessy (1981) reported that in word- initial position, the consonants which are longer are the fricatives, consonants with back- place of articulation,

and unvoiced consonants. In this study on French speech, a weak tendency for vowels to be longer after stops than after other consonants was observed.

Luce and Luce (1985) reported that vowel duration distinguished voicing for word-final stops in connected speech. In the study by Crystal and House (1988), stronger tendency was observed in English with the average length of long vowels and short vowels (152, 79 ms) following stops being much longer than following fricatives (124, 67 ms) and following nonvocalic sonorants (127 and 75 ms for long and short vowels respectively). Crystal and House (1988) examined segmental duration in English in connected speech. Among the obstruents, affricates are longer and the stops and fricatives are roughly the same, with unvoiced cognates exceeding the voiced ones. There is also a tendency for unvoiced stops to be completed than voiced stops, particularly in word- final positions. Word- initial stops are completed more often word- final stops.

van Santen (1992), based on the data on segmental models, suggested that the effects of manner and voicing were the effects seen more whereas the effects of place of articulation were negligible.

Effect of Voicing

House and Fairbanks (1953) stated that the most powerful attribute was evidenced as the voicing, followed by manner of articulation and last, the place of articulation. Lengthening of vowels before voicing is a well known phonetic – context effect seen in English. Relative duration of vowel and consonant can be also used as cue for the final sound voicing distinction (Denes, 1955).

Peterson and Lehiste (1960) investigated vowel duration in CVC type, differing with respect to the voicing of the final consonant and reported that the vowel followed by a voiced consonant is longer than the same vowel followed by an unvoiced consonant by a ratio of approximately 3: 2. They ordered vowel length according to the place of articulation and voicing characteristic, with increasing vowel duration progressively with unvoiced stops, unvoiced fricatives, nasals, voiced stops and voiced fricatives in the preceding context. But in the Crystal and House study (1988), progressive lengthening of short vowels before /t/, /s/, /d/, and /z/ was not observed.

When considering vowel durations following consonants, Fischer- Jorgensen (1964) noted that vowels after voiced stops are longer than those after unvoiced stops in word- final position. Halle and Stevens (1967) in their study in English, reported that vowels before nasals had the shortened duration. Vowels before voiced consonants had greater duration than before unvoiced ones. They attributed the difference to the vocal fold movement. According to them, during unvoiced consonants, there is wide separation of the vocal folds and can be achieved rapidly, than finely adjusted small separation for a voiced consonant.

Chen (1970) surveyed a number of languages and found all the 7 languages surveyed showed atleast a 10 % difference in vowel duration when vowels are preceded by unvoiced obstruents than before voiced obstruents or sonorants. This finding was consistent even if the vowel and consonant were word final and tautosyllabic or word medial and heterosyllabic. He also suggested that some amount of contextual durational difference is universal and some of it physiologically determined and some of it is due to the language characteristics

(e.g English, in which the difference is exaggerated by rule). He suggested that before a voiced obstruent, the sonorants and the vowel each are lengthened compared to the same categories before a unvoiced obstruent. Such a lengthening is seen to function across intervening sonorants separating a vowel and obstruent, as, for example, in *sent* and *send*.

Chen (1970) found that Russian showed comparable vowel difference but in the opposite direction with longer vowels occurring before unvoiced consonants. Similarly, Port, Mitleb and O' Dell (1981) showed that German has similar differences. Speakers of some English dialects also vary the vowel duration before voiced flaps according to underlying stop- voicing values (Fox & Terbeek, 1977). They were found to be using shorter vowels before voiced consonants. The vowel lengthening effect was more robust in the Crystal and House study (1988) with more lengthening seen for preceding vowels than sonorants. But Flege (1979) sought evidence from Arabic language in Saudi Arabia and found that the long vowel /a:/ was not significantly longer before word- final /d/ than /t/.

Therefore it is possible that languages can show no vowel durational differences (Polish and Czech and Arabic), or they can show some kind of differences that relate shorter vowels to following unvoiced obstruents (French and some English dialects) or a phonologically conditioned pattern (Russian and German). Hence, this rule cannot be placed in a universal phonetic component because it does not occur universally across languages. Rules of phonetic vowel duration as a function of voicing of a following consonant must be language specific.

The Scottish Vowel Length Rule (SVLR) predicts that a stressed vowel, atleast in a monosyllable, is phonetically short unless followed by a voiced fricative or /r/,

in which case it is long. Leyden (2002) studied the effects of SVLR in Shetland, Orkney dialects, Standard Scottish English (SSE) and Standard Norwegian. The results indicated that in Shetland dialect, the SVLR rules applies well and general shortening of long vowel occurs. On the other hand, the rule didn't appear to affect in Orkney dialect and Edinburgh speech. The reason for this was attributed to the influence of Standard English which has relatively long vowel durations preceding voiced than unvoiced consonants (Gimson, 1962). In Shetland dialect, vowel and final consonant duration are inversely related. For example, a 100- ms change in V duration results in inverse change in C^f (final consonant) duration 49 ms. But this trend was reduced in SSE and Orkney with reduction of 30 and 29 ms only respectively. In case of Norwegian, change of 57 ms was noted.

Klatt (1971a) described the generative theory of segmental duration in normally spoken English sentences. According to this theory, phonetic segments are assumed to have a property of inherent duration that could be specified. A sequence of ordered rules is then applied to modify the inherent functions as a function of the environment in which each phonetic segment appears. Rules are assumed to take the form of: "If conditions X, Y, Z are met, then change the duration of segment N by P percent". Also, a percentage- change model was assumed, according to which, the duration of the inherently short vowels (/I, è, ʌ, u/) would be changed by a smaller number of milliseconds than long vowels when followed by consonants with different manners of articulation, but the percentage of changes would be about the same. One of the rules put forth by this theory was that if a vowel is followed by an unvoiced consonant within the same word, shorten the vowel by 25% (relative to its duration when followed by a voiced

consonant within the same word) (House & Fairbanks, 1953; Denes, 1955; House, 1961; Peterson & Lehiste, 1960).

Further validating the theory, Klatt (1973) used three speakers who spoke 40 monosyllabic words and 40 related bisyllabic word. He found that the average duration ratio is 66% of its inherent duration when the consonant is unvoiced. He also gave the rule which converts an input vowel duration D_i to an output vowel duration D_0 according to the formula

$$D_0 = k\,(D_i - D_{min}) + D_{min},$$

Where k is greater than zero and depends on a particular rule. The input is initially set equal to the inherent duration of the vowel. Values of $D_{min} = 0.45$ times the inherent duration of the vowel, $k_{final\ C} = 0.4$. The author also the predicted the existence of superadditive effects of lengthening effects of phrase-final position and contrastive emphasis.

Lisker (1974) gave explanations for the variations in vowel duration in different consonant contexts:

1. According to the rule of constant energy expenditure for the syllable, vowels are longer before voiced and shorter before unvoiced consonants, as longer vowels and unvoiced consonants need greater articulatory energy.
2. Vowels are lengthened before voiced stops to allow time for laryngeal readjustments needed if voicing is to be maintained during oral closure
3. Vowels are shorter before unvoiced consonants due to articulatory closure durations required.

House (1976) noted in his study that the primary influences of vowel duration were voicing of the final consonant and the tenseness of its preceding vowel. Klatt (1976) indicated that unvoiced obstruents are longer than voiced sound and unvoiced fricatives are about 40ms longer in duration than the corresponding voiced fricatives. He also showed that the unvoiced fricative /s/ in "soo" is inherently longer than the voiced fricative /z/ in "zoo". Polish vowel duration does not vary systematically according to the voicing of the following consonant. The ratio of means of vowel duration before unvoiced to voiced consonant was 0.99. This ratio was 0. 75 and 0.79 in the experiments conducted by Sharf (1962) and Klatt (1973) for English words. This ratio increased to 0.89 (Port, 1977) when sentence context was used in English.

In Czech, another West Slavic language like Polish, a ratio of 0. 95 was obtained, indicated that a slight tendency for shortening of vowels before unvoiced consonants is present. However, this difference didn't reach statistical significance. Hence, both the West Slavic languages investigated didn't show the universal vowel shortening before unvoiced consonants.

Wolf (1978) also indicated the preceding vowel duration is an importance cue for voicing in English final stops along with formant transitions, closure, and burst. Flege (1979) sought evidence for Arabic language in Saudi Arabia and found that the long vowel /a:/ was not significantly longer before word- final /d/ than /t/. According to Walsh and Parker (1981), the reason why speakers make vowels longer before voiced consonants is that they perceive it to be longer which could be because of their physiological voicing into the consonant. Production wise, the spectrographic analysis of English words indicated that the

vowel lengthening is a function of phonological ‘voicing’ and not physiological voicing.

Hogan and Rozsypal (1980) the vowel duration differences preceding voiced versus unvoiced minimal pairs exist and is more for final fricatives than for stops or clusters.

In French, O’ Shaughnessy (1981) reported the presence of two ‘strong’ preconsonantal effects on vowel duration: the first is the lengthening before voiced fricatives and the second is the shortening before unvoiced obstruents. A weak tendency for long vowels to lengthen before voiced fricatives was noted in the Crystal and House (1988) study. Crystal and House (1988) data agreed with the same showing length of unvoiced fricatives to be longer than the voiced fricatives.

In Crystal and House (1982) study, they reported that in general for long (tense) vowels which preceded stops, duration was increased. But this effect was not seen for short/ lax vowels preceding stops or for either type of vowel preceding fricatives.

Luce and Luce (1985) reported that vowel duration distinguished voicing for word-final stops in connected speech.

Summers (1987) examined the effects of stress and final-consonant voicing on the detailed structure of articulatory and acoustic patterns in consonant– vowel–consonant (CVC) utterances in English. Results obtained indicated that decreases in vowel duration due to devoicing did not result in a reduction in the velocity or spatial extent of the articulatory gestures. Crystal and House

(1988) examined segmental duration in English in connected speech. Among the obstruents, affricates are longer and the stops and fricatives are roughly the same, with unvoiced cognates exceeding the voiced ones. There is also a tendency for unvoiced stops to be completed than voiced stops, particularly in word- final positions. Word- initial stops are completed more often word- final stops. Crystal and House also indicated that vowel duration preceding voiced stops were about 50 ms longer than those preceding unvoiced stops.

van Santen (1992), based on the data on segmental models, suggested that the effects of manner and voicing were the effects seen more whereas the effects of place of articulation were negligible. In terms of vowel independence, vowel independence is violated if there were such that the duration reduces with contextual constellations. van Santen (1992) recorded speech produced by two speakers of English and investigated the factors vowel identity, identities of the surrounding segments, position of vowel in the syllable, position of the syllable, stress status of the syllable, position of the word in the sentence (effect of phrase boundaries) and accent status of the word. 'A' may be the corrected means for position, 'B' value is for stress, *p* refers to vowel identity, *r* refers to speaking rate and *c* refers to within word context, contextual constellations are (C and *C*') and two vowels (*v* and *v'*) in which *v* is a front vowel and *v*' is a back vowel and *C* is a postvocalic velar consonant, *C'* is a labial postvocalic consonant. Parameter G is parameter of vowel independence and it increases with any contextual constellation C and where I (*v*) is the intrinsic duration of vowel *v*. α (A) multi β (S) is interaction of pitch accent and syllabic stress, θ (C_{post}) + ι (C_{post}) multi κ (*U*) refers to the interaction between post- vocalic consonant and utterance position.

$$\text{DUR (vowel } v\text{, context C)} = G\,[\,I\,(v), C]$$

$$\text{Log (DUR } (A, S, V, C_{pre}, C_{post}, W_{pre}, W_{post}, U)) = \alpha(A)\text{multi}\quad \beta\,(S) + \delta\,(V) + \varepsilon\,(C_{pre}) + \zeta\,(W_{pre}) + \eta\,(W_{post}) + \theta\,(C_{post}) + \iota\,(C_{post})\ \text{multi}\ \kappa\,(U)$$

The reverse trend was reported by Crystal and House (1988). For example, Crystal and House (1988) provided evidence that prior to velar consonants, front vowels are longer than back vowels, while they are shorter than back vowels if preceded by labial consonant.

Japanese vowels are, contrary to English, shorter when they are followed by voiced consonants (Campbell, 1992). This inconsistency implies that the effect of voicing a consonant has on the preceding vowel is not an innate factor. In case of Japanese, Sugito (1996) clarifies that a native speaker's second unvoiced consonant of 'tata' is longer than the second voiced consonant of 'dada', while the reverse is true for Chinese speakers. Research on Spanish has also shown a small average difference (18 ms) between vowels preceding voiced and unvoiced consonants.

It is hypothesized that articulation of stop consonants might represent less muscular adjustment from a physiological rest position of the vocal tract and might consequently require relatively less muscular effort than the production of sounds requiring more deviation from the rest position.

Long vs short

Peterson and Lehiste (1960) averaged the tense- lax ratio and observed that it was largest before alveolar and smallest before bilabial stop consonants, with the

velar environment showing intermediate values (1.43 before /t/ and 1.38 before /k/, and 1.36 before /p/).

Lehiste (1970) reported that, English tense vowels and diphthongs are usually longer than their corresponding lax vowels as observed between /i/ and /I/.

House (1976) noted in his study that the primary influences of vowel duration were voicing of the final consonant and the tenseness of its preceding vowel. Vowel height and following consonant type have a secondary influence on vowel duration. He had concluded that variations in vowel duration due to the primary influences are learned and language specific and that these variations are not inherent in the production of speech.

Strange et al (1976) studied the production of American English vowels in isolation and in a /pVp/ context and the task given was to read the words given. Fifteen American English speakers were included in the experiment and the authors observed that isolated vowels were on average longer than vowels in /pVp/ syllables. The data indicated the presence of a proportional difference between tense and lax vowels. It was smaller in the bilabial context (with overall tense/ lax ratio: 1.18) than in isolation (overall average tense/ lax ratio: 1.22). This trend was seen in both /i:- i:/ and /u:- u/combinations. In another study in 1979, the same group of authors used six syllabic forms (/bVb/, /bV/, /Vb, /pVp, /pV/, /Vp/) and in isolation and reported of enhanced difference ratio of 1.37 in voiced bilabial context when compared to unvoiced context (1.23) and in isolated context (1.27). Hence, the authors had concluded that the relative duration differences between tense and lax vowels were less strongly affected by place than voicing features of the adjacent consonants.

Data by Fourakis (1991) showed that the tense/ lax ratio between /i:-i/ in /bVd/ (1.38) to be larger than in the /hVd/ context (1.31). This pattern was reversed for the /u:- u/ contrast with larger difference seesn in the /hVd/ context (1.31) vs /bVd/- 1.25. Thus, the importance of front- back dimension of the vowel pair in reduction of relative duration differences was established.

In German, this ratio was smaller with the tense vowels in /dVt/ utterances were only 24 % - 40 % longer than their lax vowel counterparts because of disproportional shortening of the tense vowels, relative to the /hVt/ contexts.

In LuGanda language, a significant difference was observed between short vowel and compensatorily lengthened vowels and long vowels. The compensatory lengthened vowels were much closer to the duration of the long vowels than that of the short vowels, both lengthened and long vowels were twice in their length when compared to the short vowels, whereas a lengthened vowel was only 40ms shorter than a long vowel and had 80 % of its duration. The mean duration of the compensatorily lengthened vowel in words was 191 ms, whereas it was 73 ms in short vowel words and 237 ms in long vowel words (Maddieson, 1993).

Maddieson (1993), carried out a study in Sukuma language, and reported that the compensatory lengthened vowels fell almost halfway between the duration of the long and short vowels, and were much closer to the duration of short vowel. The mean duration of the compensatory lengthened vowel in words was 200 ms, whereas in short vowel it was 129 ms. The long vowels were over twice the length of short vowels and lengthened vowels were about one and half times the length of the short ones.

In Japanese, the ratios of long-to-short vowels was less affected by rate changes. Furthermore, the proportion of the vowel to the total word duration was found to distinguish the two vowel length categories across three rates with high accuracy. The results support the view that "relational" acoustic invariance exists that remains stable across speakers and rates (Hirato, 2004).

While there was some between-language variation in the short-to-long ratio, the long /a:/ was more than twice as long as the short /a/ in all three languages. The mean vowel duration values obtained in this study are in good agreement with the values reported in previous studies (Abramson, 1962, 1974, 2001; Gandour 1984; Hirata 2004a; Hirata & Tsukada 2009- Cited in Tsukada, 2009). Table 1 shows the vowel duration in Arabic, Japanese, Thai and Bangkok Thai.

	Arabic[1]	**Japanese[1]**	**Thai[1]**	**Bangkok Thai[2]**
Short /a/	108 (18)	82 (13)	147 (22)	140
Long /a:/	250 (54)	211 (39)	324 (45)	523
L/S ratio	2. 32	2. 54	1: 2. 20	1.374

Table 1: Average duration and SD (in parenthesis) of short and long vowels in the different languages ([1]Tsukada, 2010; [2]Narang & Misra, 2010).

The other vowels ratios are being presented in Table 2.

Vowel	**Short (ms)**	**Long (ms)**	**Short: Long**
/i/	113	470	1: 4. 16
/ɯ/	243	480	1:2
/u/	140	486	1: 3. 47
/e/	163	573	1: 3. 52
/o/	190	510	1:2.7
/ɛ/	263	630	1: 2.4
/ɔ/	280	630	1: 2.25
/a/	140	532	1:3.74
/ɤ/	326	626	1:1.92

Table 2: Average duration of short and long vowels in the Bangkok Thai.

Effect of Position

Smith (1978) noted that although durations do vary according to the consonant environment, it is the final consonant that affects vowel durational characteristics i.e., vowels preceding a voiced consonant is longer in duration than those preceding unvoiced fricatives.

Keating (1979) studied Polish voicing contrasts in word- medial position. He studied reading sample of 24 speakers and reported that the Flege (1979) sought evidence for Arabic language in Saudi Arabia and found that the long vowel /a:/ was not significantly longer before word- final /d/ than /t/.

O' Shaughnessy (1981) reported that in word- initial position, the consonants which are longer are the fricatives, consonants with back- place of articulation, and unvoiced consonants. O' Shaughnessy also suggested that in word- final position, postvocalic consonants tend to be shortened near long or low vowels and lengthened near high vowels. This is inversely said to affect the vowel duration.

Crystal and House (1988) examined segmental duration in English in connected speech. A tendency for unvoiced stops to be completed than voiced stops, particularly in word- final positions and word- initial stops are completed more often word- final stops were noted.

According to Myers and Hansen (2007), in many languages with contrastive vowel length, long vowels are systematically excluded from a domain – final position, and are replaced with short vowels there.

Other factors

i) ***Consonant cluster context***: In consonant cluster context, various studies have been done (Haggard, 1973; Klatt, 1973). They reported a phenomenon of shortening of /s/, and /p/ in /sp/ cluster than as singletons. But the effect on vowels has not been extensively studied.

ii) ***Tongue height:*** Umeda (1975) found that unvoiced fricatives tended to elongate low vowels much more than other vowels (atleast 30 ms longer). O' Shaughnessy (1981) found that duration varied with the height of the vowel. In oral vowels, the shortest vowels (90ms avg) were the high oral vowels, preceded by a phoneme other than a stop and followed by an unvoiced stop. Vowel height had a significant durational effect on the oral vowels. Compared to high vowels, mid vowels were + 32 % longer and the low vowel /a/ was + 70 % longer. O' Shaughnessy suggested that in word-final position, postvocalic consonants tend to be shortened near long or low vowels and lengthened near high vowels.

Crystal and House (1988) noted that high long vowels (/i:/, /u:/) were shorter than other long vowels but mid long vowels (/e:, o:/) didn't have the same relation with low long vowels (/a:/, /ae:/). Crystal and House (1988) provided evidence that prior to velar consonants, front vowels are longer than back vowels, while they are shorter than back vowels if preceded by labial consonant.

In Hebrew, as vowel height decreased, vowel duration increased (Most, Amir & Tobin, 2000).

iii) ***Regional/ dialectal variations:*** Clopper (2005) studied the acoustic characteristics of six regional varieties of American English vowels. Forty eight speakers spoke 11 different vowels. They represented both genders and six regional variety of American English. Results revealed consistent variation due to region, particularly with respect to the production of low vowels and high back vowels.

iv) ***Intelligibility of speech***: Vowels have longer duration in clear speech and the ratio was 1. 4 compared to unclear speech. The interpretation is that, intelligible talkers use longer word and vowel durations than the less intelligible talkers (Ferguson & Kewley- Port, 2007).

v) ***Vowel identity***: Within the same context, vowels differ markedly in duration.

vi) ***Gender***: Hillenbrand, Getty, Clark and Wheeler (1995) observed that significantly shorter vowel duration was noted for men when compared with either children or women.

The following is the summary of various factors:

1. Vocalic durations

   a) Intrinsic:

      - Tense vowels > lax vowels.
      - Vary inversely with vocalic height. Overall, consistent pattern seen [O 'Shaughnessy (1981)]

   b) Lengthening phenomena:

      i) Lengthening phrase-final words.

ii) *Lengthen before voiced consonants*: This is found in /o/ and /i/, especially prepausally [House & Fairbanks (1953), Peterson & Lehiste (1960), Luce & Luce (1985)].

iii) *Lengthen before nasal + voiced stop*. [Chen (1970)].

iv) *Lengthen before various places of articulation*.

a. Before dental > before labial/velar. [House & Fairbanks (1953)]

b. Before velar > before dental > before labial. [Maack (1953), Lehiste (1976), Peterson & Lehiste (1960)]

c. Before velars, front vowel > back vowel. [Fischer-Jorgensen (1964)]

d. Before labials/dentals, front vowel < back vowel. [Fischer-Jorgensen (1964)]

e. Before bilabial > before alveolar/velar. [Luce & Luce (1985)]

v) *Lengthen before various manners of production*.

Before stops > before fricatives, [House & Fairbanks (1953), Peterson & Lehiste (1960), Lehiste (1976)]

vi) Lengthen before combined place, manner, and/or voicing traits.

Before unvoiced stops < before unvoiced fricatives < before nasals < before voiced stops < before voiced fricatives. [House & Fairbanks (1953), Peterson & Lehiste (1960)]

vii) *Prepausal lengthening*: For short vowels, before [t] <before [s] <before [d] <before [z]. [Lehiste (1976)]

viii) *Lengthening before voiced fricatives and shortening before unvoiced obstruents.* [O 'Shaughnessy (1981)]

ix) *Following consonantal voicing*.

Vowel following [b d g] > vowel following [p t k]. [Fischer-Jorgensen (1964)]

x) *Following consonantal manner of production*.

Vowel following stops > vowel following continuants. [O 'Shaughnessy (1981)].

(4) Research in Indian languages

Researches done in Indian languages include Kannada [Rajapurohit (1982); Savithri (1986, 1989); Sreedevi (2007)], Malayalam [Velayudhan (1975); Sasidharan (1995); Ramya (2011)], Telugu [Nagamma Reddy (1988); Krishna (2009)] Hindi [Agrawal (1988)] and in Tamil [Balasubramanian (1981); Sangeetha (2009)].

All the four major Dravidian languages have been researched on earlier. In Kannada, one of the Dravidian languages spoken majorly in Karnataka, Rajapurohit (1982) studied the vowel duration in a single subject using 405 words. However, these words were not controlled for word length, post-vocalic consonants, post- vocalic voicing etc. The vowel durations are summarised in the table 3.

	Duration in (ms)		
Vowel	Initial	Medial	Final
a	67.13	71.84	68.54
a:	169. 05	157.80	138.06
I	75	60.77	80.81
i:	132	136,41	138.16
u	-	-	-
u:	-	-	-
e	114	83.16	118.85
e:	-	151.16	-
o	98	84	-
o:	196. 66	146.22	-
ə	75.14	168	-
ə:	194.	-	-

Table 3: Mean duration of vowels in Kannada (Rajapurohit, 1982).

Variables influencing the durations of Kannada vowels /a, I, u/ in initial position was investigated by Savithri (1986). The author had considered 82 trisyllabic meaningful Kannada words uttered by 6 subjects. The factors which were highly influential are the voicing, aspiration, clustering, nasality and place of articulation of the post vocalic consonant and the tongue height. Gender differences, with longer vowel duration for females when compared with males was also reported. The average duration was found to be 75.66 ms in males and 85.66 ms in females. Also, the average duration of /a/ was greater than the duration of /i/ which was greater than that of /u/. The vowels preceding unvoiced consonants were shorter when compared to those preceding the voiced consonants. Vowels preceding nasals except /m/ were shorter than those preceding non- nasal consonants. Vowels preceding aspirated consonants were longer than those preceding unaspirated consonants. With respect to place of articulation of the consonant, the vowels preceding retroflex consonants were the longest in duration and the vowels preceding velars were shortest in duration. The vowels preceding retroflex were longer than those preceding dentals, bilabials, palatals, and velars in the

progressively decreasing in duration scale. Vowels preceded by the homorganic clusters were shorter than those preceding other consonants. Table 4 shows the vowel duration as reported by Savithri (1986).

Vowels	**Vowel duration**		
	Males	Females	Average
/a/	77	86	81.5
/i/	69	97	80.5
/u/	81	79	80

Table 4: Mean duration of vowels in Kannada (Savithri, 1986).

The vowel duration ratio in Kannada, between short (80 ms) to long (180 ms) was almost twice (Savithri, 1986) and 1: 1. 6 (Savithri, 1989). On further investigations (Savithri, 1989) using ten subjects, in 100 words, concluded that in word or sentence end, the vowels were lengthened. The short vowels were lengthened by 62 ms and the long by 370 ms. The ratios of their durations in non- word- end and word- end were 1: 1. 8 for short vowels and 1: 1. 4 for long vowels, respectively. With respect to voicing features, vowels preceding voiced stops were longer than those preceding the unvoiced. The mean duration of short and long vowels preceding voiced stops were 75 and 132 ms and those preceding unvoiced stops were 66ms and 124 ms respectively. But vowels /a/ and /u/ were exceptional for this. The short vowels preceding nasal continuants were shorter than those preceding voiced stops but were longer than those preceding the unvoiced stops. Among the long vowels, those preceding the voiced stops were the longest followed by those preceding unvoiced stops and nasal continuants. The vowels preceding the semivowels /r/, /j/ and /v/ were the longest followed by those preceding fricative and stops. Vowels preceding the palatal stops were the longest followed by those preceding dentals, bilabials, velars, and retroflexed.

However, there was no significant difference in the duration of vowels. The vowel duration of the test vowel in simple syllable structure was longer than the vowel in a clustered syllable and was reduced by the nasality of the postvocalic consonant. Table 5 shows the effect of manner of articulation.

Vowels	**Stops**		**Nasals**	**Semivowels**	**Fricatives**	
	U	V			U	V
Short	66	75	67	100	72	77
Long	123	132	107	131	113	140

Table 5: Effect of manner of articulation of post- vocalic consonant on vowel duration (ms) (Savithri, 1989).

In a study on vowel duration of /i/ in /VCV/ context in Kannada speaking children, Rashmi (1985) found that both males and females showed consistent decrease in vowel duration as a function of age. Venkatesh (1995) reported that each vowel in Kannada has its own intrinsic duration with high vowels having short duration and low vowels the longest duration. Hence, vowel duration varied with the height of the tongue. Openness vs closeness and rounded vs unroundedness of the vowel also affects the duration. The short: long vowel duration ratio was almost 1: 2. He observed that females had longer vowel duration than males in long vowels only and no gender differences were obvious in short vowels.

Sreedevi (2000) studied age influences on vowel duration in Kannada language and reported that in all the three age groups studied (6- 9 years; 14-15 years and 20 – 30 years), females had longer vowel duration than males and that with increase in age, vowel duration reduced. But adults had longer vowel duration than adolescents. This difference was attributed to the sample

itself. The developmental variational trends were stronger in short than long vowels. Also, the long vowels were twice as long as the short vowels.

Malayalam is another major Dravidian language spoken in Kerala. Jenson & Menon (1972) investigated vowel duration of Malayalam vowels which contrast phonemically in length. They also reported that on an average, duration of long vowels was approximately twice than that of their short vowel counterparts and they inferred that the linguistic distinction between short and long vowels may reside in the single parameter of duration. Also, the vowel duration of short vowels increases directly in proportion to the degree of mouth opening, with the exception of /o/ which shows the longest duration.

Velayudhan (1975) in his study in Malayalam, reported a short: long ratio within the range of 1: 2. Duration of vowel, irrespective of short or long, was found to be shorter when followed by an occlusive rather than non- occlusive consonants.

A more elaborate study by Sasidharan (1995), reported that (a) there was significantly greater vowel duration in females than males in all three test positions- initial, medial and final positions, (b) in case of long vowels, the segmental durations were greater when the test vowel was in the word initial position, whereas, in the case of short vowels, the duration was longest in word final positions and shortest in the word medial position; (c) in long vowels, the segmental durations were longest among the low vowels and shortest in the case of high and mid vowels. In short vowels, segmental durations were longest among mid vowel; (d) vowel duration was found to be

longest in case of central vowels and shortest in case of back vowels; (e) the rounded vowels had shorter vowel duration compared to unrounded vowels; and (f) the duration of long/ tense vowels were approximately twice that of short/ lax vowels. It was 1: 1.89. The ratio differed when the vowel position was in initial position (1: 1. 85) vs medial position (1: 1. 93).

Reduction in vowel duration as age increases from 7- 8 years to 20 – 25 years also was noticed by Ampathu (1998) in Malayalam language. Riyamol's (2007) data revealed that vowel duration decreased with increase in height and that central vowels had longest vowel duration. It was also reported that, vowel duration in females than males. Central vowels had longest vowel duration according to her report.

Ramya (personal communication, June 5, 2011) studied the effect of post-vocalic consonants on vowel duration. Among vowels, short vowels were longer in the context of trills and long vowels in the context of laterals. And they were shortest in the context of fricatives. With respect of place of articulation, short vowels were shortest and longest in palatal and labiodental respectively. Long vowels were shortest and longest followed by velar, and retroflex respectively. The ratio of short: long was 1: 2. 19 for females and 1: 2. 38 for males with average of 1: 2. 34. In terms of position, the ratio of short and long vowels was 1: 2.34 and 1: 2.26 in initial and medial positions respectively. However, no gender difference in vowel duration was reported in this study.

Telugu is another prominent Dravidian language spoken in the South Indian state, Andhra Pradesh. Nagamma Reddy (1988) reported that, the ratio of

short and long vowel duration in word- initial to word – medial vowels in Telugu is more than 1: 2. It varies from one and half to three times depending upon the phonetic context. Her data is presented in the table 6.

Vowel	Isolation (ms) [1]	Connected speech (ms)[1]	Initial position (ms)[2]
/a/	90	50	80
/i/	70	60	86
/u/	75	45	77
/e/	100	65	87
/o/	100	55	129
/a:/	280	130	217
/i:/	250	110	178
/u:/	260	110	183
/e:/	265	110	176
/o:/	270	110	200

Table 6: Mean duration (ms) of vowels in Telugu.

([1]- Nagamma Reddy, 1988; [2]- Girija & Sridevi, 1995)

Prabhavathi Devi (1990) also observed a similar 1: 2 ratio of relative vowel duration between short and long vowels. Among vowels, open vowel /a:/ is the longest of all the vowels in Telugu. Front vowels /i: /, / e:/, are slightly longer than /u:/, /o:/. The vowel followed by a voiced consonant is longer than the same vowel followed by a unvoiced consonant. Vowel that occurs after an aspirated plosive is shorter than the one after unaspirated plosives. In Telugu, the duration of the vowel is longest when it occurs in the final position of the vowel as compared to its length in the initial and medial positions. The syllabic structure also influences the vowel duration. The duration of the vowel in the first syllable of a disyllabic word in the longest when compared to the same either in trisyllabic or tetrasyllabic words. Suprasegmental features also play a significant role in shaping vowel duration. Table 7 shows the duration of short and long vowels in Telugu (Prabhavathi Devi, 1990).

Test Vowel	Duration (ms)	Ratio
/i- i:/	93/ 223	1: 2. 3
/e- e:/	103/ 207	1: 2
/a- a:/	107/253	1: 2.3
/o- o:/	143/ 243	1: 1.6
/a- a:/	90/ 187	1: 2

Table 7: Duration of short and long vowels in Telugu [Prabhavathi Devi,1990]

In a single case study by Girija and Sridevi (1995) in Telugu, a ratio 1: 2.1 was observed between short and long vowels. The longest among short vowels is /o/ and the shortest is /u/ and the longest among long vowels is/a:/ and the shortest is / e:/. A low- open vowel was longer than a high- close vowel. The vowel before a voiced consonant was longer than the vowel before an unvoiced consonant. The vowel /a/ before unvoiced consonant was longest and /o/ is the shortest. The vowel /e/ before voiced consonant is longest and /i/ is the shortest.

Nagamma Reddy (1999) noted that shorter vowel duration is noted before consonant sequences (including geminates) in Telugu. Vowel duration is shortest when it occurs before unvoiced aspirated and longest when it occurs before voiced unaspirated consonants.

Sreenivasa Rao, Suryakanth, Gangashetty and Yegnanarayana (2001) in their study of durational analysis of Telugu language reported, duration and intonation are two most important features responsible for quality of synthesized speech (Huang, Acero & Hon, 2001). They reported that syllables with voicing nature have more duration variation compared to their unvoiced counterpart. Among the voiced and unvoiced categories, durational variations were noted based on manner and place of articulation and the vowel present.

Krishna (2009) based on his thesis on acoustic characteristics of Telugu vowels, reported the following: (a) vowels /e/ and /a:/ have longest vowel duration and short and long /i/ have the shortest vowel duration, (b) children and females had longer vowel duration compared to adults and males respectively, (c) regional differences were noted on vowel duration, (d) preceding consonant context wise, front short vowel /e/ had longer mean vowel duration when preceded by stop and affricate consonants while back high short vowel /u/ had shorter mean vowel duration. Mid long vowel /a: / had longer mean vowel duration followed by /e:/, /o:/, /u:/, and /i:/ . Back vowel /o/ had longer mean vowel duration followed by /e/, /a/, and /i/ when preceded by nasal consonants. Front high vowel /e/ had longer mean vowel duration followed by /a/ and /u/ when preceded by fricative consonants. Front vowel /e/ had longer mean vowel duration compared to mid vowel /a/ when preceded by lateral consonants. Front vowel /e/ had longer mean vowel duration compared to back vowel /u/ when preceded by trill consonants, (e) the short and long vowel ratio was 1: 2. 4 in adults, (f) with respect to the effect of place of articulation of the preceding consonant, front high short vowel /i/ had longer mean vowel duration when preceded by dental consonants followed by alveopalatal and bilabial consonants; however, long vowel /i:/ had longer mean vowel duration when preceded by velar consonants followed by alveopalatal and bilabial consonants. Front mid vowel /e/ had longer mean vowel duration when preceded by retroflex consonants followed by alveopalatal and bilabial consonants while its counterpart long vowel /e:/ had longer mean vowel duration when preceded by velar consonants followed by alveopalatal, dental and bilabial consonants, (g) mid low vowel /a/ had

longer mean vowel duration when preceded by velar consonants followed by alveopalatal and bilabial consonants but its counterpart long vowel /a:/ had longer mean vowel duration when preceded by dental consonants followed by velar, bilabial, and alveopalatal consonants, (h) back mid vowel /o/ had longer mean vowel duration when preceded by alveopalatal consonants followed by bilabial consonants and dental consonants while its counterpart long vowel /o:/ had longer mean vowel duration when preceded by retroflex consonants followed by dental, bilabial and alveopalatal consonants, (i) back high vowel /u/ had longer mean vowel duration when preceded by alveopalatal consonants followed by dental, bilabial and velar consonants while its counterpart long vowel /u:/ had longer mean vowel duration when preceded by dental consonants followed by bilabial, and alveopalatal consonants.

In Sanskrit, the duration of long vowels (180 ms) was reported to be approximately twice that of short vowels (Savithri, 1989). She reported of longer vowel duration preceding strongly aspirated stops, voiced stops and retroflex stops when compared with slightly aspirated stops, unvoiced stops and velar stops. She also found that, in Sanskrit, females had longer vowel duration when compared to their male counterparts. She also found that the vowels were longer preceding retroflex stops and shorter preceding velar stops. The duration of diphthongs was similar to the duration of long vowels.

Ganesan, Aggarwal, Ansari and Pavate (1985) studied the vowels of Hindi language in eleven speakers and summarised the data. Duration of vowels in Sanskrit and Hindi are in table 8.

Vowel	Mean duration of vowels in Sanskrit(ms) [1]		Mean duration of vowels in Hindi (ms) [2]	
	Short	Long	Short	Long
/a/	81	178	156. 5	248. 2
/i/	88	190	151. 8	286. 2
/u/	87	180	159. 2	257. 7
/r/	121	-	-	
/e/	-	196	263. 5	268. 2
/o/	-	197	159. 2	276. 1
/ai/	-	198		
/au/	-	197		

Table 8: Mean duration of vowels (ms) in Sanskrit and Hindi.

([1]Savithri, 1989; [2]Ganesan, Aggarwal, Ansari and Pavate, 1985)

Tamil is a Dravidian language spoken predominantly in the Indian subcontinent with about 66 million native speakers (Abraham & Shinu, 2003). Tamil has 14 pure oral vowels and 2 diphthongs (Balasubramanian, 1981).

Based on the survey carried on by the department of Linguistics, Annamalai University, Sakthivel (1981) (cited in CIL official website) had divided the regions of Tamil Nadu and the corresponding dialects. The regions are,

a. Northern dialect: Spoken mainly in Madras, Chengalpet, and North Arcot Districts.
b. Central dialect: Spoken mainly in Tiruchirapally, Thanjavur, and South Arcot Districts.
c. Western dialect: Spoken mainly in Salem, Dharmapuri, Coimbatore and Nilgiri districts.
d. Southern dialect: Spoken mainly in Madurai, Ramnad, Tirunelveli and Kanyakumari districts.

According in Subramoniam (cited in Kloss, 1978), the current Tamil language has two main varieties: (1) written and (2) colloquial, which is further considered to comprise of seven dialect areas. These are (a) Kanyakumari dialect, (b)

Southern dialect of the districts of Tirunelveli and Ramnad, (3) Central dialect spoken in the districts of Madurai and Trichy, (d) Western dialect of Coimbatore area, (e) Eastern dialect of the districts of Tanjore and South Arcot, (f) Madras dialect spoken in Madras city and Chengalpat and (g) Northern dialect of North Arcot district. All these regions are said to have their own dialectal variations in terms of both segmental and suprasegmental characteristics.

Balasubramanian (1981) investigated vowel duration changes in Tamil with respect to context of different consonants. The objectives were to study the relationship between vowel duration and (i) the structure of the syllables in which the vowels occur, (ii) the place of articulation of the post-vocalic consonant, and (iii) the number of syllables in the words in which the vowels occur. Four native speakers of Tamil were taken as subjects and about 700 Tamil words with oral vowels occurring in various positions formed the stimulus. The subjects were instructed to speak the target words embedded in a carrier phrase. Spectrograms and /or electrokymographic tracings were obtained of all the utterances and the vowel duration was calculated. It revealed that (a) phonologically long vowels were almost twice the phonologically short ones (b) vowel durations were longer in monosyllables than in words having more than one syllable. (c) Also vowels were longer in syllables with simple structures than in syllables of complicated structures and (d) vowels were shorted before bilabials and longest before retroflex. There was no significant difference between the durations of vowels followed by dental, palate- alveolar and velar consonants. (e) open vowels were longer than close vowels. However, it had not differentially investigated the contextual effects of all the consonants in terms of their place and manner of articulation. The author considered durational variations in different syllable

shapes only. Another study in Tamil by Sangeetha (2009) also compared the effects of consonants on vowel duration. But only plosives and few fricatives were considered in 6 vowel contexts. The results indicated that the ratio of short vs. long vowels was 1: 2.02. Within the short and long vowels, /u/ was the shortest and / a/ was the longest. High vowels were shorter compared to low vowels and mid vowels longer than front and back vowels. Vowels shortened when followed by unvoiced consonants. Vowel duration was longer before retroflex and velar consonants and shortest before palatals in short and long vowels. Also duration of vowels was longer preceding plosives. However, only nonsense words formed the stimuli in this study. Table 9, 10, 11 and 12 summarise the effect of various parameters on vowel duration.

Author	**Language**	**Findings**
Peterson and Lehiste (1960)	English	Longer following voiced
Fischer-Jorgenson (1964)	Danish	Longer following voiced
Chen (1970)	7 languages	Longer following voiced
Chen (1970	Russian	Longer before unvoiced
Flege (1979)	Arabic languages	No significant difference
Leyden (2002)	Shetland, and Orkney dialects, Scottish English, Norwegian	No difference on Orkney dialect
Campbell (1992)	Japanese	Longer following unvoiced

Table 9: Effect of voicing on vowel duration

Author	Language	Findings
Halle & Stevens (1967)	English	Short before nasals
O'Shaughnessy (1981)	French	Longer after stops
Crystal and House (1988)	English	Longer before stops than fricatives

Table 10: Effect of manner of articulation on vowel duration

Author	Language	Findings
Peterson and Lehiste (1960)	English	1:1.43
Strange et al (1976)	American English	1:1.22
Strange et al (1979)	American English	1: 1. 27
Narang & Misra (1984)	Bangkok Thai	1: 3. 74
Fourakis (1991)	British English	1:1.38
Maddieson (1993)	LuGanda	1: 3. 24
Maddieson (1993)	Sukuma	> 1: 2
Tsukada (2010)	Arabic	1: 2. 31
Tsukada (2010)	Japanese	1: 2. 54
Tsukada (2010)	Thai	1: 2. 20

Table 11: Studies on short: long ratio of vowel duration

Author	Language	Findings
House and Fairbanks (1953)	English	Velar < bilabial < alveolar
Maack (1953)	German	Shortest – bilabial Longest – velar Front vowels – Shortest – alveolars Longest – Bilabial & Velar Back vowels – Shortest – velars Longest – Bilabial
Zimmerman & Sapon (1958)	Spanish	Shortest – bilabial Longest – velar
	English	Shortest – velar Longest – alveolar
Peterson and Lehiste (1960)	English	Increased VD – Unvoiced stop, Unvoiced fricative,

		nasals, Voiced stops, Voiced fricatives Voiced plosives short vowels – velar > alveolar > bilabial Voiced plosives long vowels – alveolar > velar > bilabial
Fischer-Jorgenson (1964)	Danish	Back vowels – longest before labials and dentals Front vowels – longest before velars
Lehiste (1970)	English	Tense vowels longer than others
Suomi (1976)	British English	Voiced longest before alveolar Shortest before bilabial stops Shortest after velar
Elsendoorn (1984)	Dutch	Shortest followed by velar consonants Longest followed by dental consonant
O'Shaughnessy (1981)	French	Shortest with fricatives
Krause (1982)	English	Voiced increased as the postvocalic consonant moved posteriorly
Luce and Luce (1985)	English	Vowels preceding bilabials were longer than preceding velars or alveolars
Crystal and House (1988)	English	Vowels longer before bilabials than before alveolar or velar consonants

Table 12: Effect of place of articulation on vowel duration.

The review indicates temporal measures in various languages including Indian languages. However, in Tamil, the number of subjects studied by Balasubramanian (1981) and Sangeetha (2009) were less. Hence, a detailed durational analysis of vowels in Tamil including more subjects is essential. In this context, the present study was designed and investigated the effect of preceding/ following consonants on duration of vowels in Tamil.

The aims of the study were multifold and as follows:

1) To investigate the effect of

   (a) Manner of articulation

   (b) Place of articulation, and

   (c) Voicing features of consonants on vowel duration.

2) To compare the difference in vowel duration between genders.

3) To investigate the effect of postvocalic and prevocalic consonant on the

   a. Degree of mouth opening (open, spread, rounded),

   b. Tongue height (high, mid and low),

   c. Tongue advancement (front, central and back), and

   d. Length of the vowels (long and short).

CHAPTER III

METHOD

MATERIAL: The test stimuli consisted of a list of 428 bi- or tri-syllabic meaningful non-emotional commonly used Tamil words. The vowels included the short vowels /a/ (low mid), /i/ (front high), /u/ (back rounded), /o/ (mid back), /e/ (mid front) and their long counterparts. The consonantal contexts used included plosives [bilabial (/p, b/), alveolar (/t̪ , d̪ /), retroflex (/ʈ ɖ/) and velar (/k, g/)]; affricates (/ c, ʤ /); laterals (/ l̪ , l, ɭ /); trills (/r, ɾ /); nasals (/m, n, ɲ, n̪ , ɳ , ɳ/); approximants (/j, v/) and fricative in alveolar (/s/) position.

The words were chosen from the Tamil dictionary, Tamil phonetic reader and from popular magazines and books. They were given for familiarity rating to two native speakers of the language and the familiar words were taken up for the study. This resulted in a corpus of 428 words which was constituted by words native to Tamil language only and few borrowed/ loanwords which are regularly used during colloquial speech. Of them, 147 had consonants in the initial position, 228 in the medial position and 58 in the final position. Appendix I shows the word list.

SUBJECTS: Fourteen native Tamil speakers (seven males and seven females) in the age group of 18-25 years participated in the study. None of them had any speech, language, hearing, neurological or organic problems. They were native speakers and residents of Tamil Nadu. They all had minimal educational qualification of 10^{th} standard. Subjects residing in the areas of Kanyakumari were considered for the study in order to control for the dialectal variations. Since Umeda (1977) had indicated that the duration of consonants are also affected by the syllable stress, emphasis and position of the consonant in a word, the participants were selected in such a way that

the prosodic variation (such as stress, tone, emphasis, and vocal effort) remain constant for all participants and specific feature dependent segment duration does not have any effect on the target phoneme.

PROCEDURE: Prior written consent from the subjects was obtained. Each word was written on a card. The subjects were seated in a comfortable position in a quiet environment. The cards were visually presented to the participants one at a time and they will be instructed to read each word five times. All the readings were audio-recorded using an omni- directional microphone held constant at 10 cm from the mouth. Trials were given for the ease of the subjects initially when required. The subjects were allowed a rest period of 5 minutes in between recordings if required to reduce strain on their part. The recorded words were given for correctness identification to 2 trained SLPs and only correctly uttered samples were considered for analysis. The samples were digitized at 11,100 Hz sampling frequency and stored onto the computer memory. Three of the five repetitions of each word were used for analysis.

Analysis

Acoustic analysis: A total of 17976 [428 (words) * 3 (times) * 14 (speakers)] tokens were analysed in this study. Using Praat software (Boersma & Weenink, 2009), wide band Spectrograms and waveforms of target words was displayed. For this study, Vowel duration was measured as the duration difference between the onset and offset of the vowel. Vowel onset was determined by the first steady visible pulse of the steady formant structure characteristic for the vowel. Vowel offset was determined similarly by the last steady visible pulse of the formant structure.

In the initial position, the vowel duration following the first consonant was measured and for the medial and final positions, the vowel duration preceding the target consonant was measured.

Statistical analysis: All statistical analyses were done using a commercially available SPSS 17.0. The statistical analysis included descriptive statistics, Repeated measure ANOVA followed by Post- Hoc measures and Paired- t test were used to find out the effect of the various variables and their interaction.

CHAPTER IV

RESULTS

The purpose of the study is to investigate the effect of postvocalic and prevocalic consonant on the vowel duration in Tamil. Hence, the data analysed was classified and computed in order to find out the effect of consonants on vowel duration in three positions, in different place and manner of articulation and voicing. Also, an attempt was made to analyse vowel duration variations with reference to (a) degree of mouth opening (open, spread, rounded), (b) tongue height (high, mid and low), (c) tongue advancement (front, central and back), and (d) length of the vowels (long and short).

Initially Independent *t* test was performed to compare the gender differences in vowel duration. Results indicated no significant difference between vowel duration in the two genders [t = 1. 282, (p > 0. 05) & t= 2. 52, (p > 0. 05)]. However, females had longer vowel duration than males in both short and long vowels. /e/ and /e:/ were longer and /u/ and u: were the shortest. Table 13 and 14 show the mean duration (ms) and standard deviation of short and long vowels.

	Males	**Females**	**Average**
/a/	81. 86 (6. 37)	95. 27 (10.1)	88. 57 (10.57)
/i/	75. 03 (4. 80)	88. 23 (12. 5)	81. 67 (11. 39)
/u/	75. 30 (4. 24)	83. 17 (13. 48)	79. 23 (10. 43)
/e/	90. 57 (8. 07)	109. 35 (11. 59)	99. 96 (13.66)
/o/	91. 48 (5. 63)	103. 5 (10. 64)	97.52 (10.31)
Avg	82. 85 (5. 37)	95. 91 (11. 27)	89. 38 (10. 85)

Table 13: Mean duration (ms) and standard deviation (in parenthesis) of short vowels.

	Males	Females	Average
/a:/	196. 52 (12. 06)	211. 06 (33. 14)	203.79 (34. 84)
/i:/	182. 60 (13.72)	208. 20 (34. 84)	195. 45 (28. 72)
/u:/	179.62 (13. 1)	194. 36 (38. 20)	186. 99 (28. 49)
/e:/	196. 70 (15. 38)	219. 34 (36. 28)	208. 02 (29. 23)
/o:/	185. 77 (12.94)	204.11 (34. 69)	194. 94 (26. 89)
Avg	188. 24 (12. 27)	207. 43 (35. 22)	197. 84 (27. 22)

Table 14: Mean duration (ms) and standard deviation (in parenthesis) of long vowels.

Since there was no significant difference between males and females combined data was used for future analysis.

a) Effect of Position

The positions considered were initial, medial and final. In initial position, the effect of preceding consonant was studied and in the medial and final positions, the effect of postvocalic consonant was studied.

Results of 2- Way repeated measures ANOVA indicated significant difference between positions. [$F(2, 24) = 8.435$, $p < 0.005$]. Vowels in final position were longer compared to initial and medial positions.

Paired – *t* test showed significant difference between the initial and medial positions [$t = 7.35$, $p < 0.005$], medial and final positions [$t = 6.036$, $p < 0.005$] for short vowels and medial and final positions [$t = 7.35$, $p < 0.005$] for long vowels. Table 15 shows the mean and standard deviation of vowel duration in three positions.

Short	Initial	Medial	Final
/a/	89.25 (10.16)	82.27 (10.97)	97.30 (12. 43)
/i/	77.00 (9.9)	81.30 (11.90)	86.79 (16. 10)
/u/	78.33 (9.24)	74.82 (10.70)	79.08 (13.21)
/e/	101.29 (11.2)	95.33 (15.55)	95.33 (15.51)
/o/	106.59 (10.22)	83.39 (9.90)	109.29 (15. 59)
Avg	**90. 49**	**83. 42**	**93. 56**
Long			
/a: /	203.94 (26.84)	193.08 (24.92)	201.47 (20. 92)
/i: /	179.22 (23.19)	205.18 (33.40)	207.71 (21. 26)
/u: /	180.22 (26.80)	185.82 (30.26)	204.65 (17. 89)
/e: /	202.99 (27.29)	214.40 (18.08)	216.79 (16. 84)
/o: /	199.26 (25.18)	192.49 (29.64)	195.38 (16.80)
Avg	**193. 13**	**198. 19**	**205. 20**

Table 15: Mean (ms) and standard deviation (in parenthesis) of vowel duration in initial, medial and final positions.

/i/, /u/ and /u/, /i:/, /u:/, and /a:/ were the shortest in initial, medial, and final positions, respectively. /o/, /e/, and /e/, and /a:/, /e:/ and /e:/ were the longest in initial, medial and final positions, respectively. Significant interaction between Position * Vowels [F (1, 1894) = 26. 27, (p = 0. 00)] was observed.

b) Effect of Manner of articulation

Results of 2- Way repeated measures ANOVA indicated significant difference between manner of articulation {F [(5, 60) = 6. 413, p= 0.00]}. Also, significant interaction effect of the Vowel * Manner of articulation ($p < 0.05$) was observed. Further, results of paired *t* test indicated significant differences between all manners of articulation ($p < 0.05$). Vowels were shortest in the context of plosives and longest in the context of trills. Table 16 shows the duration of short and long vowels in the context of consonants.

Manner	Short vowel	Long vowel
Plosives	83. 90 (9. 2)	185. 33 (24. 54)
Fricatives	89. 58 (13. 01)	198. 09 (46. 21)
Nasals	89. 02 (10. 21)	200. 13 (27. 12)
Laterals	91. 79 (13. 7)	207. 17 (26. 39)
Trills	94. 06 (10. 94)	210. 60 (16. 29)
Approximants	91. 45 (13. 14)	204. 43 (36. 34)

Table 16: Mean duration in ms and standard deviation (in parenthesis) in the environment of various manners of articulation of consonants.

c) Effect of Place of articulation

Results of 2 way repeated measures ANOVA showed a significant difference between vowels in various places of articulation [F (5, 12598= 58, p= 0.00)]. There was significant interaction between vowel * place of articulation (p= 0.00). Results of Paired *t* test showed a significant difference between all places of articulation ($p < 0.05$). Table 17 shows duration of vowels as preceded/ followed by consonants in various place of articulation.

Place	Short vowel	Long vowel
Bilabial	81.47 (9.16)	188.21 (29.72)
Labiodental	97.93 (16.21)	201.93 (24.56)
Alveolar	90.67 (12.37)	185.35 (27.71)
Dental	89.88 (10.22)	201.50 (22.14)
Palatal	86.48 (9.71)	204.28 (33.71)
Retroflex	90.73 (11.85)	219.61 (31.81)
Velar	88.46 (10.61)	183.98 (27.46)

Table 17: Mean (ms) and standard deviation (in parenthesis) of the long and short vowels as preceded/ followed by consonants in different place of articulation.

d) Effect of Voicing

Results of 2- way repeated measure ANOVA indicated significant effect of vowel [F (9, 3483= 41. 99), p = 0. 00)], and voicing [F (1, 12 = 510), p = 0. 00)].

Significant difference was noticed for both the vowel types (short and long) between the voiced and unvoiced condition ($p < 0.05$). The vowels, both short and long, were longer in the voiced consonant context.

There was significant interaction between vowel * voicing [$F(9, 12 = 24.13)$, $p = 0.00$)]. Table 18 shows the vowel duration in the context of voiced and unvoiced consonants.

Voicing	Short vowel	Long vowel
Voiced	90. 24 (10. 53)	200. 61 (21. 35)
Unvoiced	82. 11 (9.91)	185. 46 (31. 35)

Table18: Vowel duration of short and long vowels in the context of voiced and unvoiced consonants.

e) Degree of mouth opening

With respect to the degree of mouth opening, vowels are classified as open, spread and rounded. /a / and /a: / are open vowels, /I /, /i: /, /e / and /e: / are spread vowels and /o /, /o: /, /u / and /u: / are rounded vowels. Descriptive statistics was computed and among short vowels, spread vowels were the longest and among long vowels, open vowels were the longest. Rounded vowels were the shortest. In short vowels, open vowels were significantly shorter than spread vowels ($t = 2.275$, $p < 0.05$). In long vowels, both open and spread vowels were significantly longer than the rounded vowels ($p = 0.00$). Table 19 shows the vowel duration and SD.

	Short	Long
Open	88.57 (10.69)	203.79 (25.12)
Spread	90.79 (12.33)	201.73 (28.70)
Rounded	88.38 (10.08)	190.96 (27.43)

Table 19: Mean and standard deviation (in parenthesis) of vowel duration (ms).

f) Tongue height

With respect to the tongue height, vowels are classified as high, mid and low vowels. /a/ and /a:/ are low vowels, /i/ , /i,: /, /u/, and /u:/ are high vowels and /o/, /o:/, /e/ and /e:/ are mid vowels. Results of paired *t* test indicated significant difference between vowel duration with various places of articulation. High vowels were the shortest among short vowels and long vowels. Table 20 shows the vowel duration and SD

	Low	Mid	High
Short	88.57 (10.69)	98.74 (11. 75)	80.43 (10. 56)
Long	203.79 (25.12)	201.48 (27.96)	191.22 (28. 24)

Table 20: Mean and standard deviation (in parenthesis) of vowel duration (ms).

g) Tongue advancement

With respect to the tongue advancement, vowels are classified as front, mid and back vowels. /a/ and /a:/ are mid vowels, /i/, /i: /, /e/, and /e:/ are front vowels and /o/ & /o:/ and /u/ & /u:/ are back vowels. Among the short vowels front and mid vowels were significantly different from each other (t= 2. 275, p= 0.04) and in long vowels, back vowels were significantly different from front and mid vowels (p= 0.00). Back vowels were significantly shorter than other vowels. Table 21 shows the vowel duration and SD.

	Front	Mid	Back
Short	90.79 (12.33)	88.51(10.69)	88.38 (10.08)
Long	201.73(28.70)	203.79 (25.12)	190.95 (27.43)

Table 21: Mean and standard deviation (in parenthesis) of vowel duration (ms).

CHAPTER- V

DISCUSSION

The results of the present study indicated several points of interest. First of all, there was ***no significant difference between genders on vowel duration,*** though females had a tendency for longer vowel duration than males. This is in consensus with Ramya (2011) in Malayalam, who also observed a trend for longer vowel duration in females though not statistically significant. Gender difference was significantly observed in majority of the earlier literature with longer vowel duration females than in males in Kannada (Savithri, 1986), Telugu (Krishna, 2009), Sanskrit (Savithri, 1989), English (Zue & Lafferiere, 1979) and Australian English (Cox & Palethorpe, 2004). It is also in consonance with the results in Navajo language (Mc Donough, Ladefoged & George, 1993) in which there was no significant difference between genders. Increased vowel duration for females can be attributed to the reduced rate of speech in females which contributes to increased segmental durations (Cox & Palethorpe, 2004).

Second, ***/u/, /u:/ were the shortest vowels and /e / and /e:/ were longest vowels whereas /e:/ was the longest*** in all three positions. In is partially in consensus with studies done earlier (Savithri, 1986 & Venkatesh, 1995 in Kannada; Prabhavathi Devi, 1990 and Girija & Sridevi, 1995 in Telugu; Balasubramanian, 1981and Sangeetha, 2009 in Tamil; Sasidharan, 1995 and Ramya, 2011 in Malayalam).

Third, ***the ratio between short and long vowels was 1: 2. 14 in initial, 1:2. 38 for medial and 1: 2. 04 for final position.*** That is, ***the long vowels were slightly more than twice the length of short vowels.*** Similar results were also observed in Kannada, (Savithri, 1986, 1989 with 1: 1. 6 ratio), Malayalam (Sasidharan, 1995- 1: 1.89 mean,

1: 1.85 in initial position and 1: 1.93 in medial position; Ramya, 2011- 1: 2.34 in initial and 1: 2.26 in medial), Telugu (Nagamma Reddy, 1986- more than 1: 2; Girija & Sridevi, 1995- 1: 2.1; Krishna, 2009 with 1: 2. 4 ratio) and Tamil (Sangeetha, 2009- 1: 2.02). However, it is not in consonance with the studies done in English. The results suggest language differences in vowel duration.

Fourth, ***vowel duration in final position was longest compared to medial and initial positions***. This was consistently seen in both the gender groups and in the two types of vowels- long and short. This agrees well with Prabhavathi (1990) who also observed that in Telugu, the duration of the vowel is longest when it occurs in the final position as compared to its length in the initial and medial positions and partly with Sasidharan (1995) who observed longer vowel duration in word final positions in the case of short vowels in Malayalam. Sasidharan (1995) also indicated the presence of longest vowel duration in the word initial position in long vowels in Malayalam which contradicts the results of the present study. The reason for increased vowel duration in final position could be attributed to the fact that most of the words in final position in Tamil language were monosyllables or bisyllables compared to the other two positions which had trisyllables also in them. Savithri (1989) concluded that in word or sentence end, the vowels in final position were lengthened in Kannada. This is supported by other authors (Gaithenby, 1965 ; Klatt, 1976; Smith, 1978) who found that the syllable/ syllables at the end of a sentence were longer than they would be within an utterance in English. Lengthening in word final position cues word ending.

Fifth, ***vowels were longest in the context if trills and shortest in the context of plosives.*** This is in partial agreement with studies in Kannada by Savithri (1986, 1989), Ramya (2011) and Sangeetha (2009) in Tamil. According to Savithri (1986), vowels preceding nasals except /m/ were shorter than those preceding non- nasal consonants. She also reported of longer vowels preceding the semivowels /r/, /j/ and /v/, followed by those preceding fricative and stops (Savithri, 1989). It is in contrast with the results of O' Shaughnessy, 1981, who reported vowel lengthening before stops. It has been suggested by O' Shaughnessy (1981) that the reason why vowels associated with fricatives are shorter is that in French, fricatives tend to have longer duration when compared to other consonants. In Tamil, trills are the shortest speech sounds and hence vowels in their context might be lengthened.

Sixth, ***short vowels were shortest and longest in the context of bilabials and labiodentals, respectively. Long vowels were shortest and longest in the context of velars and retroflex, respectively.*** It agrees partially with the results of study done by Balasubramanian (1981), in which vowels were shorted before bilabials and longest before retroflex, and Sangeetha (2009) who reported longest vowel duration before retroflex and velar consonants and shortest before palatals in short and long vowels. Ramya (2011) had similar findings in Malayalam with short vowels being shortest and longest in the context of palatal and labiodental respectively. Long vowels were shortest and longest followed by velar, and retroflex respectively. Similar results were also obtained in Kannada, by Savithri (1989) who stated that vowels preceding the palatal stops were the longest followed by those preceding dentals, bilabials, velars, and retroflex. It was in partial agreement by another study in Kannada (Savithri, 1989) in which, the vowels preceding retroflex consonants were the longest in duration and the vowels preceding velars were shortest in duration. The vowels

preceding retroflex were longer than those preceding dentals, bilabials, palatals, and velars in the progressively decreasing in duration scale.

In Sanskrit, (Savithri, 1989) vowels were longer preceding retroflex stops and shorter preceding velar stops. O' Shaughnessy (1981) stated that, since back consonants are longer in French, it could have resulted in shorter vowels following it, as observed in this study also in Tamil. Also, the longer vowel duration before retroflex could be due to time delay in moving the tongue from the vowel target to the consonant target. Following vowel articulation the tip of the tongue should be curled back to touch the hard palate for the articulation of the retroflex consonant which is a difficult articulation.

Seventh, ***vowels preceding/ following unvoiced consonants were shorter than those preceding the voiced consonants.*** The results are in accordance with Aitken's Law (Aitken 1962 and 1977), according to which, if a vowel is followed by a voiceless consonant within the same word, the vowel is shortened by 25% (relative to its duration when followed by a voiced consonant within the same word) (House & Fairbanks, 1953; Denes, 1955; House, 1961; Peterson & Lehiste, 1960). It is also in accordance with the Indian studies done by Savithri (1986) in Kannada, Sangeetha (2009) in Tamil, Ramya (2011) in Malayalam and Prabhavathi Devi (1990) in Telugu. Similar trend has been observed in Danish- (Fischer- Jorgensen, 1964; English (Halle & Stevens, 1967; Crystal & House, 1988) and French (O' Shaughnessy, 1981). The various reasons that have been attributed to this are the difference in the vocal fold movement (Halle & Stevens, 1967), combination of physiology of person, linguistic characteristics and certain degree of universality in languages (Chen, 1970), maintaining constant energy expenditure, time delay in laryngeal readjustments for voicing, and articulatory adjustments (Lisker, 1974). But

this in contrary to other languages like Russian (Chen, 1970), some English dialects (Fox & Terbeek, 1977), German (Port et. al., 1981), Japanese (Campbell, 1992; Sugito, 1996) which showed the opposite trend. Therefore it is possible that languages can show no vowel durational differences (Polish, Czech and Arabic), or they can show some kind of differences that relate shorter vowels to following voiceless obstruents (French and some English dialects) or a phonologically conditioned pattern (Russian and German). Hence, this rule cannot be placed in a universal phonetic component because it does not occur universally across languages. Rules of phonetic vowel duration as a function of voicing of a following consonant might be language specific.

Eighth, ***rounded vowels had the shortest duration, with spread and open vowels being longer in duration.*** This is in concordance with the previous studies in Tamil (Balasubramanian, 1981 and Sangeetha, 2009), Kannada (Savithri, 1986), Telugu (Prabhavathi Devi, 1990; Girija & Sridevi (1995).

Ninth, ***high vowels were shorter in duration in both short and long vowels and mid and low vowels were longer***. This result is also in consonance with the previous studies in Tamil (Balasubramanian, 1981 and Sangeetha, 2009), Kannada (Savithri, 1986), Telugu (Krishna, 2009) and Malayalam (Sasidharan, 1995) and other languages of the world like English (Umeda, 1975; Crystal & House, 1988); French (O' Shaughnessy, 1981); Hebrew, (Most, Amir & Tobin, 2000).

The results of the present study have contributed to the literature on vowel duration in Tamil. Using the data, a model for vowel duration in Tamil can be proposed. However, caution should be exercised to interpret the model to the dialect

investigated in the study. Future research on vowel duration in spontaneous speech, in context, and other dialects of Tamil is warranted.

CHAPTER VI
SUMMARY AND CONCLUSIONS

The present study investigated the effect of different consonantal contexts on vowel duration in Tamil. The consonantal contexts studied were, seven place of articulation – bilabials, labiodentals, alveolars, dentals, palatals, retroflex and velars and six different manners of articulation- plosives, fricatives, nasals, trills, laterals, and approximants , and voicing. Ten vowels - 5 short (/a/, /i/, /u/, /e/, / o/) and their long counterparts (/a: /, /i: /, /u: /, /e: /, /o: /) - were chosen for the study and all possible vowel consonantal combinations allowed according to the phonotactics of Tamil language were taken. The stimuli included 428 words with vowels in all three positions- initial, medial and final. The words as read by 14 native Tamil speakers were audiotaped and analysed for vowel duration.

The results showed many points of significant interest. First of all, there was ***no significant difference between genders on vowel duration,*** though females had a tendency for longer vowel duration than males.

Secondly, the consistent pattern seen was that ***/u/, /u:/ were the shortest vowels and /e / and /e:/ were longest vowels whereas /e:/ was the longest*** in all three positions.

Thirdly***, the ratio between short and long vowels was 1: 2.14 in initial, 1: 2.38 for medial and 1: 2.04 for final position.*** That is, ***the long vowels were slightly more than twice the length of short vowels.***

Fourth, ***vowel duration in final position was longest compared to medial and initial positions***.

Fifth***, vowels were longest in the context if trills and shortest in the context of plosives.***

Sixth, ***short vowels were shortest and longest in the context of bilabials and labiodentals, respectively. Long vowels were shortest and longest in the context of velars and retroflex, respectively.***

Seventh, ***vowels preceding/ following unvoiced consonants were shorter than those preceding the voiced consonants.***

Eighth, ***rounded vowels had the shortest duration, with spread and open vowels being longer in duration.***

Ninth, ***high vowels were shorter in duration in both short and long vowels and mid and low vowels were longer***.

The results of the present study have contributed to the literature on vowel duration in Tamil. Using the data, a model for vowel duration in Tamil can be proposed. However, caution should be exercised to interpret the model to the dialect investigated in the study. Future research on vowel duration in spontaneous speech, in context, and other dialects of Tamil is warranted.

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APPENDIX- I

STIMULUS LIST

INITIAL POSITION

	/a/	**/a:/**	**/i/**	**/i:/**	**/u/**
/p/	/pandə/	/pa:kkə /	/picci/	/pi:rangi/	/puram/
/b/	/bandə/	/ba:ma/	/binɖu/	/bi:ma/	/buvana/
/ ʈ /	/ ʈadi/	/ ʈa:di/	/ ʈiɳɳai/	/ ʈi:ʈʈi/	/ ʈuɳi/
/ɖ /	/ ɖanam/	/ ɖ a:nam/	/ ɖ inam/	/ ɖ i:ram/	/ ɖurai/
/ ʈ/	/ ʈan /	/ ʈaan/	/ ʈin /	-	-
/ ɖ/	/ ɖappa/	-	/ ɖipan/	-	/ ɖum ɖum /
/c/	/cakkai/	/ ca:kku /	/cinnə/	/ci:nni/	/cukku/
/ʤ/	/ ʤannal/	/ ʤa:n/	/ ʤilla/	/ ʤi:ɾakam/	/ ʤuɾam/
/k/	/kannə/	/ka:ɳa/	/kirukkə/	/ki:ɾai/	/kuɾal /
/g/	/ganam/	/ga:na/	/giri /	/gi:ʈa/	/guɳam/
/m/	/maɾam /	/ma:ɖam/	/miɖi/	/ mi:ɖ i /	/ mugam /
/ɳ /	/ ɳaɳɖa/	/ ɳa:ɖam/	/ ɳiʈʈam/	/ ɳinɖə /	/ ɳugam/
/n/	-	-	-	-	-
/ ɲ/	/ ɲamali/	/ɲa:lam/	-	-	-
/ ŋ/	-	-	-	-	-
/ ɳ/	-	-	-	-	-
/ɾ/	/ ɾasam/	/ ɾa:sa /	-	/ ɾi:ɖi /	/ ɾusi/
/r/	-	-	-	-	-
/v/	/varam/	/va:ram/	/viral/	/vi:ran/	-
/ ɻ /	-	-	-	-	-
/ ɭ /	-	/ ɭa:dam/	/liŋgam/	-	/luŋgi/
/l/	-	-	-	-	-
/j/	/jamuna/	/ja:mini/	-	-	/jugam/
/s/	/sakkaɾam/	/sa:mbar/	/siram/	/si:rum/	/suram/

	/u:/	**/e/**	**/e:/**	**/o/**	**/o:/**
/p/	/pu:ra:n/	/perum/	/pe:rum/	/poɳ gal/	/Po: ɳ gal/
/b/	/bu: n̪d̪i/	/bena/	-	/bommai/	/bo:d̪ai /
/ t̪ /	/ t̪u:nd ə /	/ t̪eru/	/ t̪e:di/	/ t̪odu /	/ t̪o:du /
/ d̪ /	/ d̪ u:ram/	-	/ d̪e:van/	/ d̪oni/	/ d̪o:ni/
/ ʈ /	-	/tennis/	-	-	-
/ ɖ /	/ ɖu:jat/	-	/ ɖe:viʈ /	-	-
/c/	/cu:də /	/cennai/	/ce:r/	/colla/	/co:r/
/ʤ/	-	/ ʤeja /	/ ʤe:i /	-	/ ʤo:r /
/k/	/ku:rai/	/kedu/	/ke:d ə /	/kombu/	/ko:ɾ t̪ t̪ə /
/g/	-	/ged̪ai/	-	-	/go:bi/
/m/	/mu:ʈʈə /	/met̪ t̪ai/	/me:l/	/moɭ i/	/mod̪:i/
/ n̪ /	/ n̪u: l̪ /	/ n̪eruppu/	/ n̪e:ɾu/	/ n̪oɾukkə /	/ n̪o: ɳɖ ə /
/n/	-	-	-	-	-
/ ɲ/	-	/ ɲ e ɳ ɖ ə /	-	-	-
/ ɳ /	-	-	-	-	-
/ ŋ /	-	-	-	-	-
/ɾ/	/ ɾu:bai /	-	/ ɾe:ʃan/	/ ɾomba /	/ ɾo:ʤa /
/r/	-	-	-	-	-
/v/	-	/vedi/	/ve:di/	-	-
/ ɭ /	-	-	-	-	-
/ l̪ /	-	/legu/	/le:gijam/	/lokka/	/lo:gam/
/l/	-	-	-	-	-
/j/	/ju:d̪as/	/jerumai/	/je:su/	/josija/	/jo:ga:m/
/s/	/su:rijan/	/serrupp ə /	/se:r/	/sol/	/so:ɾ/

MEDIAL POSITION

	/a/	**/a: /**	**/i/**	**/i: /**	**/u/**
/p/	/aparna/	/a:pai/	/tippu/	/i:ppi ɳ i/	/upava:sam/
/b/	/aba:jam/	/sabai//	/vibaʈʈə /	/ ʈ i:bam/	/ubaɾi/
/ ʈ /	/ aʈul /	/a:ʈiram /	/ ciʈ ʈi /	/si: ʈa /	/ puʈija /
/ ɖ /	/ aɖai /	/ka:dai /	/i ɖai/	/ki:ɖam/	/uɖam/
/ ʈ /	/naʈpu/	/a:ʈci/	/iʈli/	/ i:ʈʈi/	/ku:ʈʈi/
/ ɖ /	/aɖai/	/a:ɖai/	/iɖai/	/i:ɖə /	/uɖai/
/c/	/accam/	/ a:carijam /	/kicci /	/ ki:cci /	/kucci/
/ʤ/	/aʤiʈa/	/ ma:ʤik /	/ niʤam /	/ i:ʤipt /	/ buʤam /
/k/	/ ʈakadu/	/ka:kam/	/ ʈikil/	/vi:kkam/	/kukai/
/g/	/agaɭ/	/a:gum/	/igaɭvu/	/i:gija/	/mugil/
/m/	/amaɾ/	/a:mai/	/imai/	/ ci:mai/	/umiḻ /
/ ɳ /	/ saɳɖi/	/ sa:ɳɖi/	/ iɳɖə /	/ i:ɳtə /	/uɳtan/
/n/	/anaɖi/	/ a:nanɖi /	/inbam/	/i:nṭə /	/unnai/
/ ɲ/	/a ɲɲa:nam/	/a:ɲa:/	-	-	-
/ ɳ /	/ aɳil/	/ a:ɳi /	/ iɳai /	/ vi:ɳ /	/ uɳḍə /
/ ŋ /	/vaŋgi/	/va:ŋgi/	/iŋ gum/	/ni:ŋ gə /	/ puŋgu /
/ɾ/	/aɾi/	/ a:ɾi /	/iɾakkam /	/i:ɾam /	/ uɾi /
/r/	/ari/	/a:ri /	/ irai /	/ si:rum /	/ uram /
/v/	/avan/	/a:vaɭ /	/ival /	/i:vu/	/uvamai/
/ ɻ /	/aɻa/	/ a:ɻa /	/iɻanɖa /	/ i:ɻanam /	/ uɻavan /
/ ɭ /	/aɭari/	/a:ɭai/	/iɭai/	/ki: ɭ/	/uɭagam/
/l/	/kalai/	/ka:lai/	/ilamai/	/ni:lam/	/puli/
/j/	/kajal/	/ka:jam/	/ijal/	/i:ja/	/ujir/
/s/	/asai/	/a:sai/	/isai/	/i:sal/	/usa:r/

	/u:/	**/e/**	**/e:/**	**/o/**	**/o:/**
/p/	/ t̪u:pam/	/ t̪eppa/	/e:ppam/	/ t̪oppai/	/ t̪o:ppu /
/b/	/t̪u:bam/	/kebi/	-	/obad̪ija/	/go:bi/
/ t̪ /	/ju:t̪an/	/et̪il/	/ e:t̪an/	/pot̪ t̪i/	/po:t̪ai/
/ d̪ /	/u:d̪a /	/ed̪il/	/e:d̪o/	/ pod̪u/	/ po:d̪um/
/ ṭ /	/ku:ṭṭi/	/keṭṭə /	/ke:ṭṭə /	/koṭṭai /	/ko:ṭṭai/
/ ḍ /	/u:ḍaḷ /	/eḍai /	/e:ḍə /	/oḍə /	/o:ḍə /
/c/	/ku:ccam/	/eccɔ /	/te:ccɔ /	/koccam/	/ko:cca/
/ʤ/	/ pu:ʤai /	/keʤan /	/ t̪eʤa: /	-	/po:ʤanam /
/k/	/ku:kural/	/ekipt̪u /	/se:kai/	/sokka/	/so:kam/
/g/	/mu:gam/	-	/e:ga/	/pogai/	/po:gum/
/m/	/u:mai/	/eman/	/e:ma:li/	/romba/	/o:mam/
/ n̪ /	/u:n̪tə /	/ t̪on̪d̪i/	/ en̪ta/	/ ve:niḷ̪/	-
/n/	/u:n/	/t̪enṭal/	/t̪e:nil/	/onṭə /	/po:nṭu /
/ ɲ/	-	-	-	-	-
/ ṇ /	/u: ṇ /	/eṇbaḍu /	/e:ṇ i/	/soṇai/	/ko:ṇal/
/ ŋ /	/ t̪u:ŋgə /	/eŋgu /	/ e:ŋg ə /	/ poŋgu /	/o:ŋgə /
/ɾ/	/u:ɾin/	/eɾi /	/e:ɾaḷ̪ am /	/oɾumai /	/o:ɾam /
/r/	-	/erumb ə /	/e:r ə /	-	-
/v/	/ku:vi/	/evan/	/e:vu/	-	/o:vijan/
/ l̪ /	/u:l̪ijam /	/ oḷiga /	/eḷu /	/eḷuṭṭə /	/e:l̪ai /
/ l̪ /	/ku:li/	/e l̪i/	/ e:l̪am/	/o l̪akkai/	/o: l̪ai/
/l/	/u:lai/	/elija/	/e:lanam/	/olija/	-
/j/	-	/mejmai/	/me:jpan/	/koijsu/	/o:jvu/
/s/	/u:si/	/esi/	/e:si/	/kosu/	/o:sai/

FINAL POSITION

	/a/	/a: /	/i/	/i: /	/u/
/p/	-	-	-	-	-
/b/	-	-	-	-	-
/ ʈ /	-	-	-	-	-
/ ɖ /	-	-	-	-	-
/ ʈ /	-	-	-	-	-
/ ɖ /	-	-	-	-	-
/c/	-	-	-	-	-
/ʤ/	-	-	-	-	-
/k/	-	-	-	-	-
/g/	-	-	-	-	-
/m/	/nagam/	/muga:m/	-	-	/varum/
/ ɳ /	-	-	-	-	-
/n/	/ ɳan/	/ ɳa:n/	/min/	/mi:n/	/mun/
/ ɲ/	-	-	-	-	-
/ ŋ /	/maŋ /	/ ka:ŋ /	/viŋ /	/ vi:ŋ /	/puŋ /
/ ŋ /	-	-	-	-	-
/ɾ/	/ nagaɾ /	/na:ɾ /	/ ujiɾ /	/ni:ɾ /	-
/r/	-	-	-	-	-
/v/	-	-	-	-	-
/ ɻ /	-	/ va:ɻ /	/ ɳamiɻ /	/ki:ɻ /	-
/ ɭ /	/kadaɭ/	/kaija:ɭ/	/kujiɭ/	/ ci:ɭ/	/puɭ/
/l/	/kaigal/	/na:l/	/a:pil/	-	/mul/
/j/	/kaj/	/ka:i/	/pij/	-	-
/s/	-	-	-	-	-

	/u:/	**/e/**	**/e:/**	**/o/**	**/o:/**
/p/	-	-	-	-	-
/b/	-	-	-	-	-
/ t̪ /	-	-	-	-	-
/ d̪ /	-	-	-	-	-
/ ʈ /	-	-	-	-	-
/ ɖ /	-	-	-	-	-
/ʧ/	-	-	-	-	-
/ʤ/	-	-	-	-	-
/k/	-	-	-	-	-
/g/	-	-	-	-	-
/m/	-	-	-	-	/po:giro:m/
/ n̪ /	-	-	-	-	-
/n/	/pu:nu:l̪/	-	/pe:n/	/pon/	-
/ ɲ/	-	-	-	-	-
/ ɳ /	/ t̪u:ɳ /	/eɳ /	/ pe:ɳ /	/poɳ /	-
/ ŋ /	-	-	-	-	-
/ɾ/	/vu:ɾ /	-	/ se:ɾ /	-	/so: ɾ/
/r/	-	-	-	-	-
/v/	-	-	-	-	-
/ l̩ /	/su:l̩ /	-	-	-	-
/ l̪ /	/ n̪u:l̪/	/ n̪el̪/	/me:l̪/	/kol̪/	/ko:l̪/
/l/	/ku:l/	/cel/	/ke:l/	/kol/	/ko:l/
/j/	-	/nej/	/pe:j/	/poj/	/ n̪o:j/
/s/	-	-	-	-	-