TIMING IN SPEECH : A REVIEW OF LITERATURE

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The paper reviews the literature on durational models, role of duration in speech perception and factors affecting the duration of speech sounds. In the course of discussion, several areas warranting further research have been identified. Further, the paper briefly dwells on the notions of ancient Indian scholars on durational models.

Human speech is characterized by sloppy and precise articulatory movements with the acoustic speech wave as result. In order to perceive and comprehend this message, the listener not only has to notice the important events, but also has to neglect unimportant distortions. Duration is an important aspect of the message comprehended. Several studies on the durational structure of speech sounds have been conducted which reveal marked variations as well as small variations in the segmental durations *(STL, QPSR,* 1975).

Variations in segment duration are important cues of acoustic variability in the realization of linguistically identical units (Nooteboom, 1973).

Study of the systematic variation? in vowel duration may possibly reveal some aspects of the organization of the mental structures of language, particularly those that are not studied by the conventional methods of linguistics (Nooteboom, 1973).

Physical measurements on the articulatory and acoustic aspects of speech production indicate the regularities in the timing of speech. Those regularities are found to be language specific and thus reflect learned aspects of verbal behaviour. A study of such regularities may lead to the formulation of rules which model part of the knowledge, the speaker has about his language. The physical measurements would be the best way to gain insight into the structures of language (Nooteboom 1973).

Further, durational data could be used to understand the nature and organization of speech production, speech perception and phonological theory (Khozhevnikov and Christovich, 1965). The duraticnal patterns reflect the speaker's mood, speaking rate and the locations of the emphasized material. The phonetic identity of different types of segment is cued by their duration (Klatt,

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1976). Perceptual studies of natural and synthethic speech that have been altered with regard to temporal aspects (Haggins 1972 ; Nooteboom, 1971) indicate that the listener can perceive very small changes in segmental duration as deviant. Duration plays another kind of role in speech perception. The speech sound heard is determined by the duration of gradually changing speech event such as a formant transition (Liberman *el at,* 1956: Suzuki, 1970).

It has been shown that duration can effectively disambiguate syntactically ambiguous sentences even in the absence: of cues provided by fundamental frequency and pauses (Lehiste, Olive and Streeter, 1976).

In addition, durational dats may of immense use in a appled research areas, *viz.,* automatic generation of speech for a reading machine for the blind and the automatic recognition of speech from the acoustic waveform.

The present paper reviews the literacey on durational models factors affecting the segmental duration, role of duration in speech perception and contribution of Sanskrit literature to the duraiton models.

Durational Models

Several models have been proposed to explain the way in which control over duration is achieved. Currently 2 models are recognized, viz... "Comb model ", " Chain model ".

The " Comb model " holds that the units of speech are executed according to some underlying pre-programmed time schedule, *i-e-,* the duration of speech sounds to be uttered are determined before they are produced. For example, if the speech sound [a] is to be produced the duration for which it is to be produced is determined before its production.

According to the " Chain model',ther is no underlying time program or a given speech gesture is executed after the preceding gestures have- been completed successfully (Ohala, 1973), *i.e.,* the duration of the speech sound to be produced is not pre-determined.

Ohala (1973) suggests the "Chain model" for long-term timing and the "Comb model" for the short-term timing.

Khozhevnikov and Christovich (1965) presented evidence for the "Comb model ". They stated that the durational structure of a sentence is- pre-planned and that the open syllable is an important unit in this process. Pre-planned sequential commands change the articulatory processes, which results in compensatory effect in speech production This further gives rise to lengthening of the **preceding** segment when the following is shortened or *vice versa.*

Ohala (1975) questions these findings and claims that a chain model is as relevant as a Comb model. If the Comb model is the most basic model, compensatory effects in speech perception to minimize the influence of local disturbances while decoding the message is needed. If Chain model is true, there is no immediate need for such a compensatory behaviour *(STL, QPSR,* 1975).

Some models describe the way in which timing information takes place in brain (Allen, 1972 ; Creelman, 1962 ; Triesman, 1963 ; Michon 1967). This timing information has been explained by Allen (1972) in two ways. Allen (1972), using the vowel duration, states that the commands to produce a vowel articulation could include the information : " Simultaneous with the start of the commands for the vowel, send out a neutral impulse along a nerveloop type, known to the Motor Control program, specific to vowels with this particular duration, continues to issue commands for this vowel production until impulses arrive back on the return branch of this loop "• According to him " the neutral loop would act like a delay line, with each class of articulatory durations having its own fixed delay between initiation and cessation of neuromotor command" (Allen, 1972).

The second model involves a " Clock and a Countdown number ". The vowel command would include the instruction " simultaneous with the start of the commands for this vowel, begin counting down cycles of the speech time clock ; when ' n' cycles are complete, the vowel is complete ". The number would be computed by the brain for each articulatory duration (Allen, 1972).

Other models involving time quarter have been developed by Creelman (1962), Triesman (1963) and Michon (1967), Creelman (1962) suggests a Poisson source and says that no constantly running " internal clock " will account for the data of his experiments. Triesman (1963) suggests a " Pacemaker " or " Clock like generator " whose rate may be subject to small errors. Michon (1967) assumes a " Pacemaker source " whose rate of pulsation is highly task dependent, to account for a variety of periodicities in his data.

" Another model called the " Condenser model " suggests that the duration may be stored in terms of the interval of time, a given condenser with a given charge needs to decharge to a certain threshold level. Therefore each unit which is to *be* assigned a duration is assigned a charge for a condenser. Thus duration rules would be opsrations on the charge of condensers " *(STL, QPSR,* 1975).

At present none of the models on timing information in speech behaviour could be accepted or rejected for lack of empirical evidence. It could be hypothesized that a model for the storage of timing information must have the possibility of storing in a duration with an accuracy of a few milliseconds and must have a higher absolute accuracy for shorter intervals than for longer intervals. However, the question of the accuracy of the descriptive model still remains.

Factors Influencing Duration in Speech Production

Durations of different segments vary widely depending upon several factors. Klatt (1976) classified these factors as follows :—

(1) Extralinguistic factors,
(2) Discourse level factors,
(3) Semantic factors,
(4) Syntactic factors,
(5) Phonetic factors and
(6) Physiological factors.

1. Extralinguistic Factors

Under the extralinguistic factors Klatt (1976) includes speakers' mood, their physical Condition and speaking rate. Further age and sex are included in the present review.

Speaker's Mood and Physical Condition

Speaker's mood and his physical condition affects the durational patterns largely. Williams and Stevens (1972) have shown that actors, attempting to simulate various emotional states, speak differently in different emotional conditions. They speak very slowly when angry and slower than normal when expressing fear or sorrow.

Speaking Rate

Change in speaking rate tends to change the durational patterns. For example it has been shown that a good fraction of the extra duration goes into pauses when speakers slow down (Goldman-Eislcr 1968). Huggins (1964) has shown that increase in speaking rate shortens vowels, and consonants. It is also accompanied by phonological and phonetic simplifications.

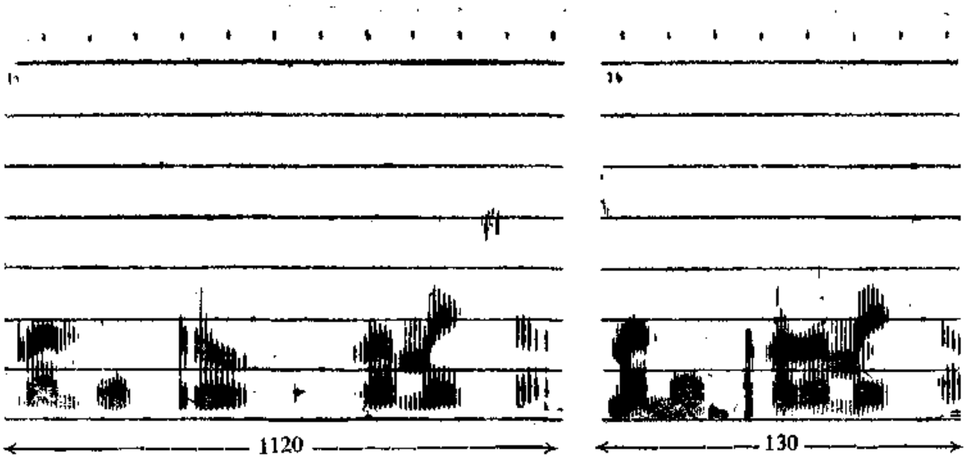
Figure 1 depicts the effect of speaking rate on segment durations

(As the original spectrograms are not available spectrograms of a Kannada speaker, SA are used as examples. However, it should not be confused that the findings hold good for Kannada language unless It is specified.)

Gay *et al.* (1974) states that the consonantal gestures are strengthened when the speaking rate is increased because of the complex reorganization of the motor commands to the articulators. However i he motor commands for vowels are not enhanced.

Age

Sweetings (1980) found that the vowel duration increased with the age of the speaker.



Ettralinguistic factor : speaking rate

1 (a.) Normal rate of speech

1 *(b.)* Fast rate of speech

Fig. 1. Broad-band spectrograms are shown to illustrate the change induration (in m.sec.) of speech sounds in normal (1«) and fast (16) rate of speech in the sentence/nan hesru ramesa/.

According to Dismoni (1974), the mean duration of vowels in the voiceless consonant environment remains constant, whereas that in the voiced consonant environment increases with the age of the speaker.

Sex

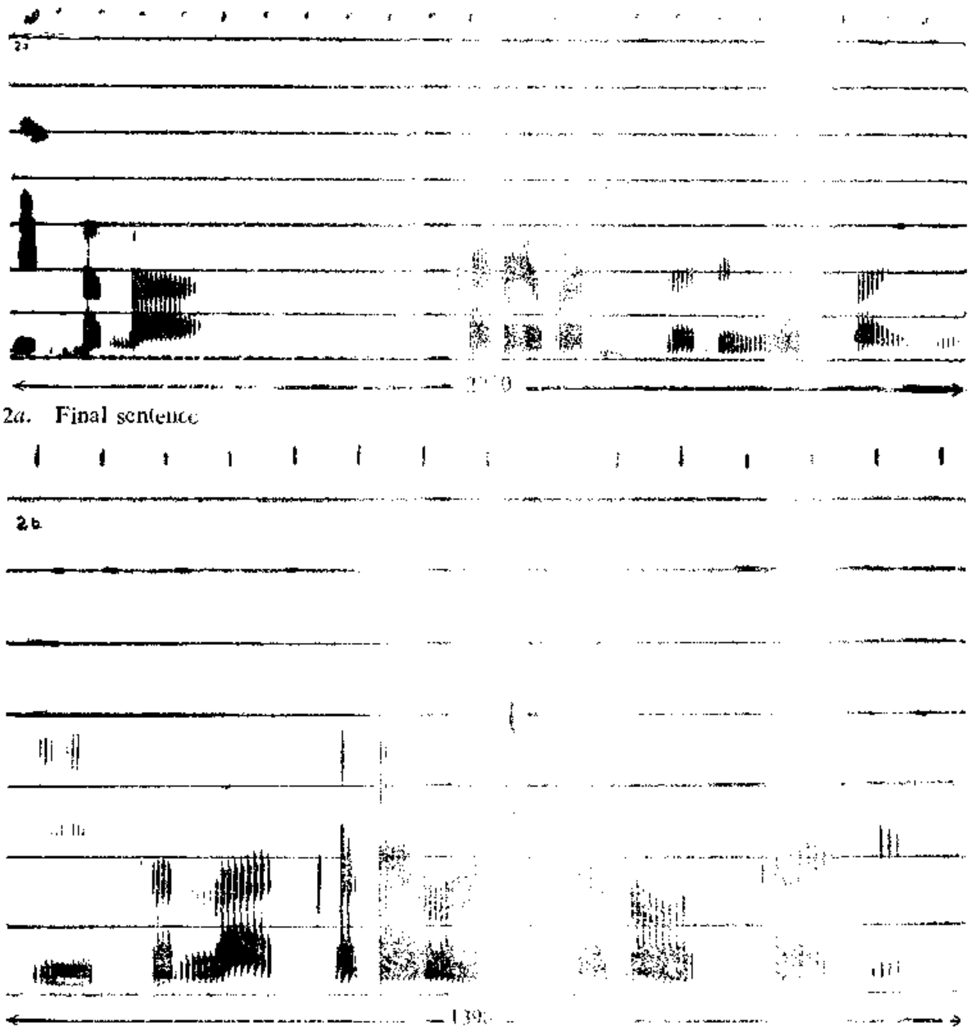
Zue and Lafferirre (1979) observed that longer durations characterized female speech. This phenomenon was also observed in earlier investigations by the present author on Sanskrit vowels (1983) and Kannada vowels (1985a, 1985b).

2. Discourse—Level Factors

The sentence of a read passage will be longer than the non-final sentence of the passage (Klatt 1976). Spectrograms in Fig. 2 show the difference in duration between the final sentence (2260 m.sec.) and the non-final sentence (1390 m.sec). It has been observed by Klatt (1976) that the vowel duration has primary importance only in phrase-final environments. The final syllable of the sentence is lengthened when compared to the non-final syllable. It is as if the speakers tend to slow down at the ends of the conceptual unit. An example of the difference between the final and non-final use of the syllable [a] is presented in Fig. *2a.* The final syllable **[a]** is 120 m.sec. longer than the non-final syllable **[a].**

3. Semantic Factors

Emphasis and semantic novelty are listed as semantic factors affecting the speech sound duration.



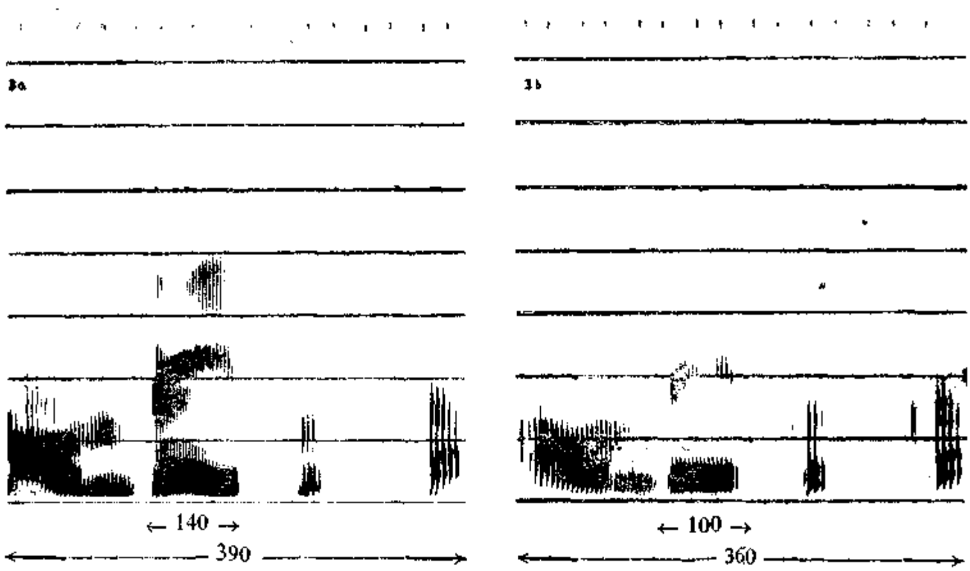
Discourse level factor : Final sentence lengthening

Fig. 2. Broad-band spectrograms illustrate the lengthening of the final sentence.of a read passage, (a) Final sentence, (b)non- final (medial) sentence.(Isala kade varsadalli odta idini.)

**Note :* Figs, 2*a* and2b are not in the same scale.

Emphasis

The first semantic factor to be considered is emphasis or contrastive stress. The acoustic correlate of emphasis is an increase in the duration of the word. The spectrograms in Fig. 3 indicate that there is as much as 30m.sec increment in the duration of the word emphasised when compared to the non-emphasised word.



Semantic factor : Emphasis

3a. Stress in the word 3b. No stress.

Fig. 3. Broad-band and narrow-band spectrograms indicating the increase in the duration (in m. sec.) of the stressed syllable [e] In the word /Ava]ade/.

Semantic Novelty

An unusual word *would* be longest, the first time it appears in a connected discourse inferring that semantic novelty has an influence on segmcntal durations.

4. Syntactic Factors

Phrase-structure L engthening

Gaitenby (1965) found that the syllable or syllables at the end of a sentence are longer than they would be within an utterance. The same was observed by Klatt (1976).

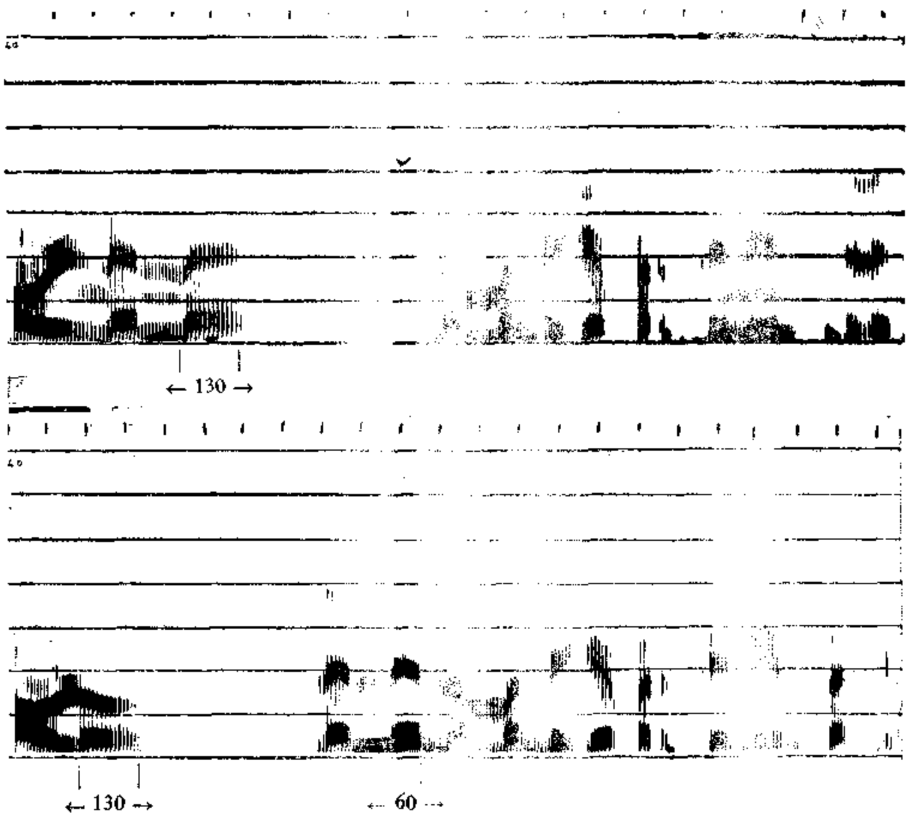
An example is given in Fig. 2.

Prepausal Lengthening

The syllables before the pause are lengthened when compared to syllables in other positions. In Fig. 4 it Could be observed that the syllables [u] and [e] are 60 m.secs longer before pause.

Martin (1970) showed that segments tended to be lengthened in spontaneous speech just prior to major grammatical constituent boundaries. Lengthening was observed at the ends of noun phrases and conjoined or embedded clauses.

It may be a natural tendency to slow down at the end of all motor sequences or the speaker may learn to lengthen the prepausal syllables to enable the listener



Syntactic factor : Prepausal lengthening

4a. Prepausal lengthening of the syllable [e]; word final lengthening of the syllable **[e]**

4b- prepausal lengthening of the syllab[u].

Fig. 4. Broad-band spectrograms depicting the lengthening of the [u]and [e] in the

sentences *(a)* Avalu nenne nammalige bandidlu/and (b) Avalu nenne nammalige (a)

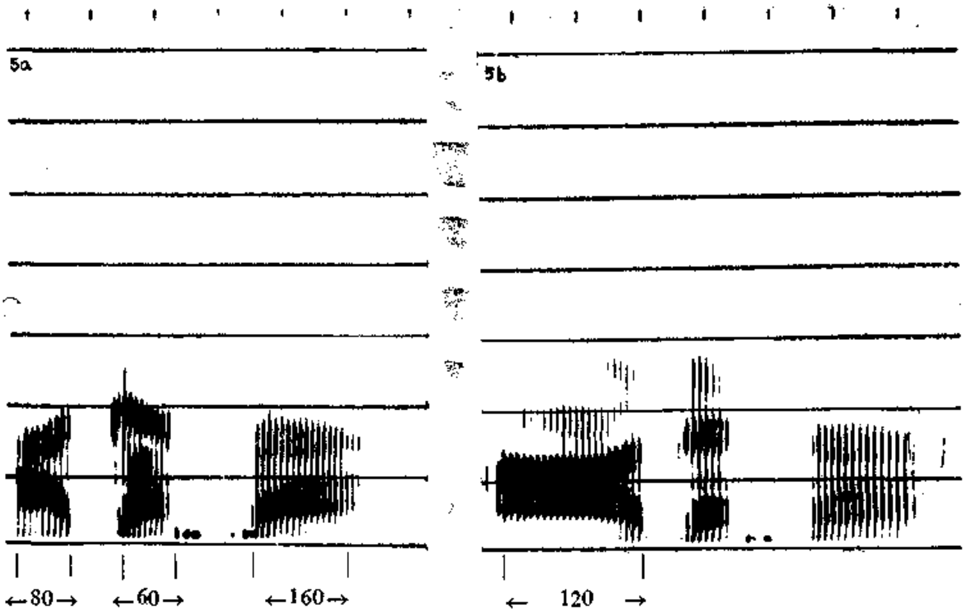
and word-final syllable lengthening of [e] in /nenne/ (b). decode the message better or

it is oroba'-Iv icu t[1] to the genenn (kcelaration of motor activity at the ends of

sp ak;n; uols 'Ulatt, 1976).

Word -final Lengthening

The word-final syllables are somewhat longer in duration the non-final syllables (Oller, 1973; Klatt, 1975), The examples can be observed in the spectrograms of Fig. 4 and **Fig.** 5. In Fig 4a the duration of final [e] is 130 m.sec. whereas the duration of non-final [e] is 60 m.sec. In Fig. 5, the final syllable **[a]** is 160 m.sec. longer than the non -final syllable [a] which is 60 m.sec. long.



Syntactic factor : Word-final lengthening
5a. Word-final lengthening of the vowel [a]   56. Short/long contrasts.

Fig. 5. Broad-band spectrograms showing the lengthening of the word-final syllable [a] in the word /agasa/ and the durational contracts of the short *(a)* and long vowel *(b)* in /agasa/ and /agasa/

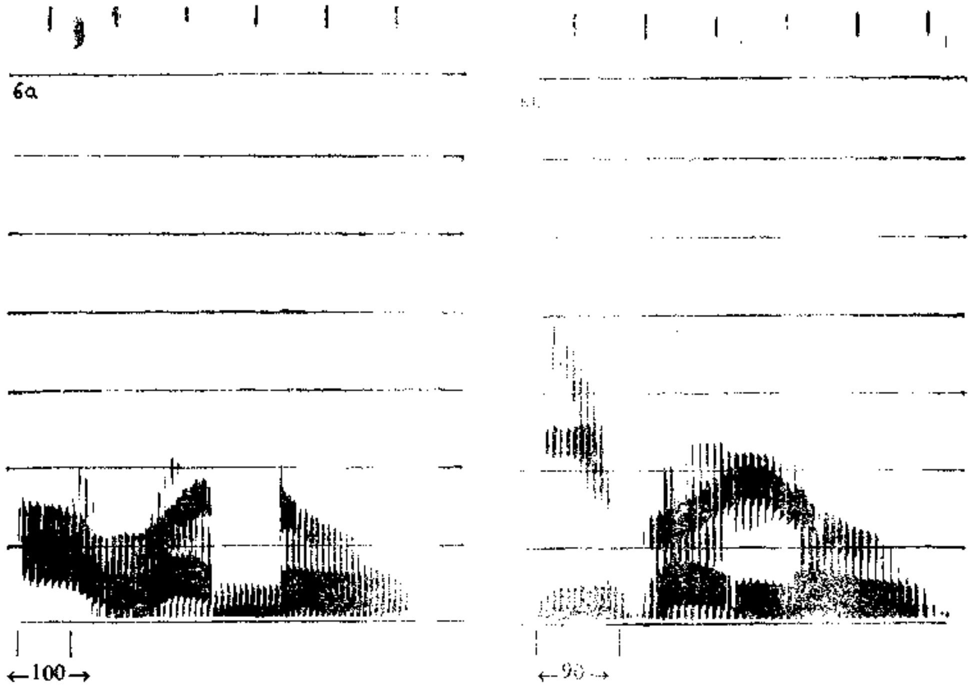
5. Phonetic Factors

Inherent Phonological Duration

Each phonetic segment has its own intrinsic phonological duration. Some vowels are short and some vowels long and some are over-long. Figure 5 depicts the duration of short and long counterparts of the vowel **[a]** which are 80 and 220 m.sec. respectively.

The duration of the vowels appears to be related to tongue height. Other factors being equal a low vowel is longer than a high vowel. Experimental evidence for this emerges from studies on English, German, Danish, Swedish, Thai, Lappish, Spanish (Klatt, 1976) and Kannada (Savithri, 1985). An example is shown in Fgi. 6 in which the duration of the low vowel **[a]** is 10 m.sec. more than that of the high vowel **[i].**

The reason for this might be found in the physical processes. It is a known fact that velar height and the degree of closure of the velopharyngeal port varies systematically with vowel articulation. In general, the velum is characteristically lower and the port more open for low vowels than for high vowels. This takes more time thus explaining the longer duration for low vowels.



Phonetic factor : Tongue height

6a. Low vowel 6b. High vowel

Fig. 6. Broad-band spectrograms are shown to illustrate the duration of low-vowel [a] in /avanu/ (a) and high vowel [ij /ivalu/(b).

Duration of consonants depend- on many factors. The aspirated consonants are longer (160 m.sec.) than the unaspirated consonants (110m.sec) as shown in Fig. 7.

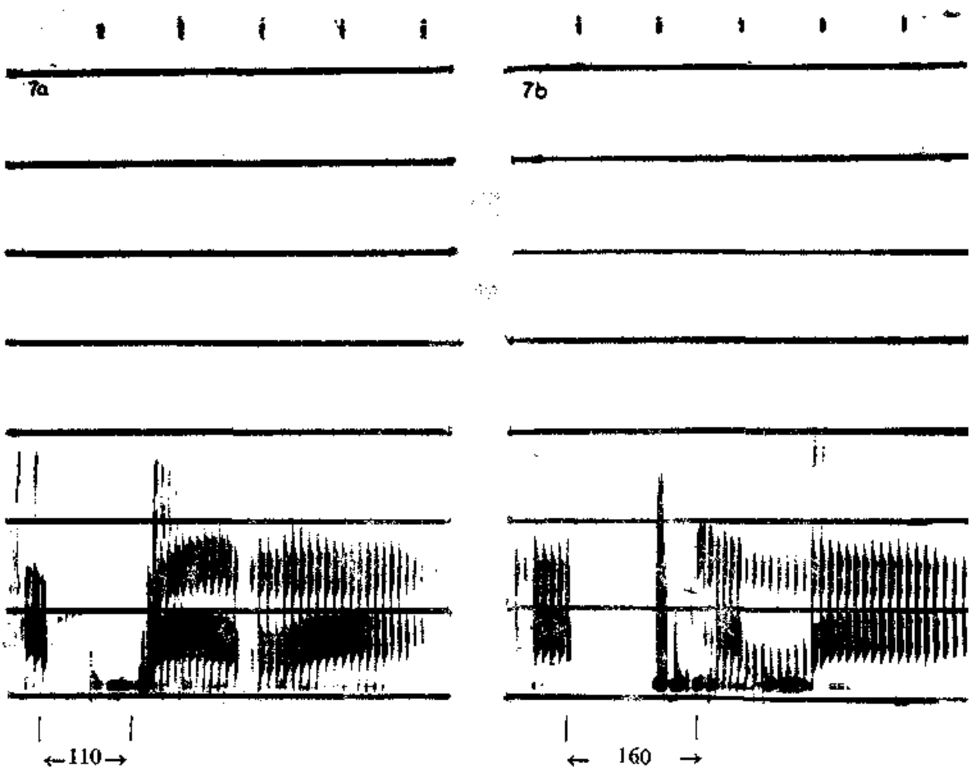
The duration of the voiceless consonant is more than that of the voiced (Klatt, 1976 ; Weismer and Sthathopoulous, 1979).

In the example given in Fig. 8 *viz.atavi/* and /adavi/ the duration of the voiced consonant [d] is 70 m.sec whereas that .of the voiceless consonant *[t]* is 110 m.sec.

Word initial consonants are longer than non-initial consonants (Klatt, 1976),' In Kannada it was observed that the duration of consonants in the medial position was less than those in the initial position (Rajapurohit, 1982). Fintoft (1961) found that the unvoiced fricatives of Norwegian speech sounds were always longer than any other consonants in. Sanskrit it was observed that the retroflex consonants were the shoriest in duration when compared to consonants with other places of articulation (Savithri. 1983)

Effect of Linguistic Stress :

Stress pattern of an utterance modifies the segmental duration. Stressed vowels are generally longer than unstressed vowels (Parmenter and Trevino.



Ponetic factor : Aspiration

(7a) Unaspirated [p]. (7b) Aspirated [ph].

Fig. 7. Broad-band spectrograms are shown to illustrate the change in duration of [p] in aspirated *(a)* and unaspirated (6) conditions, in the words / apara / and / aphala /.

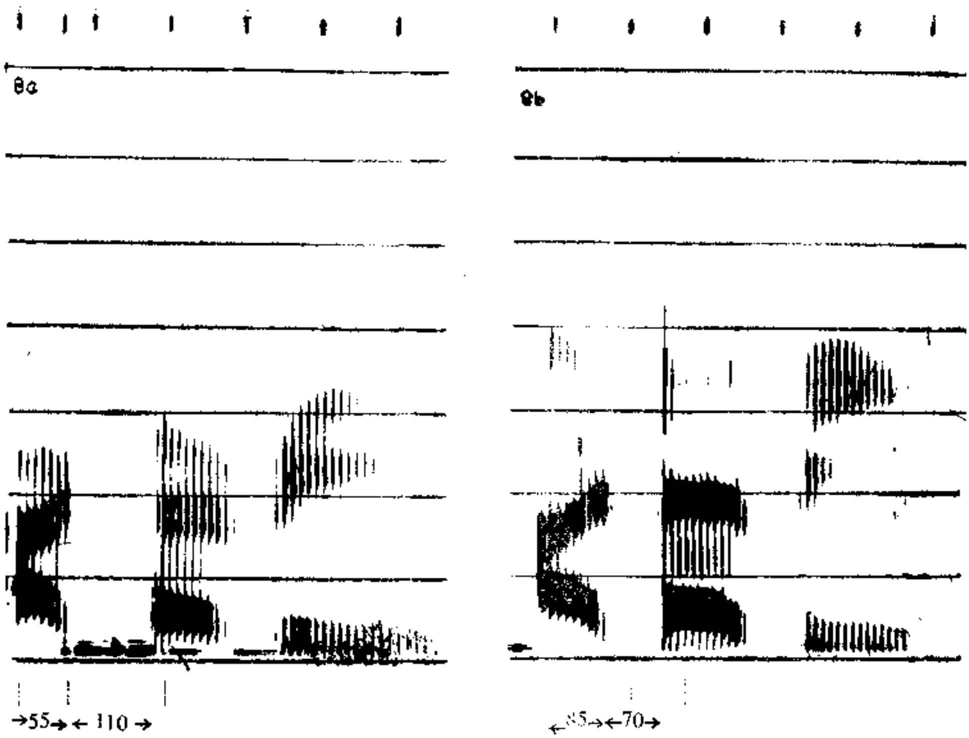
1936 ; Oiler, 1973; Lehiste 1975a). In Fig. 3a the stress is on the vowel [e] which is 40 m.sec greater than the unstressed vowel [e] in Fig. *3b.*

In Dutch, the duration of the stressed vowel decreases with increasing number of syllables that remain to be produced in the word. The effect is more pronounced in stressed long vowels than in stressed short vowels and stronger for isolated words than for embedded words. (Nooteboom, 1973).

Effect of Post-vocalic Consonants on the Vowel Duration and Effect of Preceding and Following Vowels on Consonants Duration :

Vowels ate longer if followed by voiced than if followed by voiceless consonants (Delattre 1962 ; Lyberg, 1981). An example is shown in Fig. 8 in which the vowel preceding voiced [d] is 30 m.sec. longer than that preceding the voiceless [t].

The reasons for this as hypothesized by Halle and Stevens (1967) is that the vocal cords are widely open for the voiceless consonants, whereas for the voiced sounds fine adjustments are required. These fine adjustments consume more time than the wide separation for the voiceless consonants because of



Phonetic factor : Voicing

(8a) Voiceless cansonant [t] (8b) Voiced consonant [d]

Fig. 8. Broad-band spectrograms are provided to illustrate the longer duration for the voiceless consonant [t] *(a)* in the word . /atavi/ when compared to the voiced consonant **[d]** *(b)* in the word ,/adavi/ and the effect of post -vocalic consonant on the vowel.

which vowels are lengthened preceding voiced consonants. Further, the velopharyngeal width will be longer for voiced stops, when compared.to the voiceless. This widening of the velopharynx for voiced stops requires more time which lengthens the vowels preceding voiced stops.

In German, it has been observed that the front vowels ate longer before labials and velars than before dentals and back vowels are longest before velars (Maack, 1953). House and Fairbanks (1953) found that English vowels are generally longer before labials or velars. Kenneth (1976) found that vowel duration in tricative environment is longer than in the plosive environment.

Nooteboom (1973) has shown that (1) the consonant duration is affected by the number of syllables following. Consonantal duration decreases as the number of syllables following increases , Further, the consonants preceding short vowels are more affected than consonants preceding long vowels ;

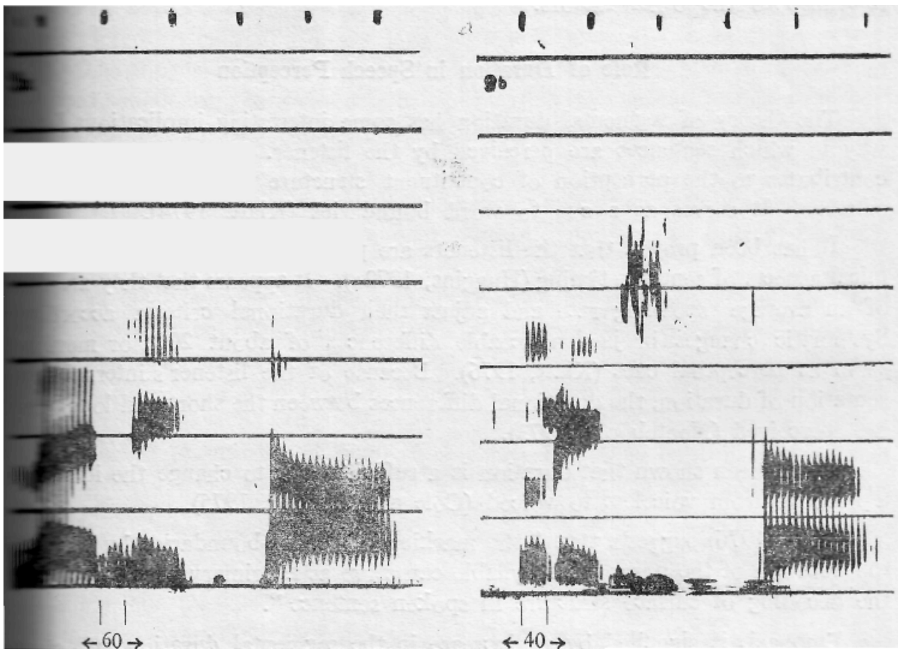
(2) Consonants occuring in the initial position of the word are **about 15-30** m.sec. longer than those in the non-initial position, provided it is **not** followed by a stressed vowel ;

(3) Consonants preceding stressed vowels having a pitch accent show an INCREASES in duration of about 25 m.sec. ; and

(4) Consonants when preceding a pause are lengthened.

segmental Interactions :

Consonants tend to become short in the environment of clusters. The duration of the consonant [1] is 20 m.sec shorter in the cluster [kl] when compared to its duration in non-cluster in Fig. 9.



Phonetic factor : Segmental interactions

(9a) Consonant [1] in the word /laiita/. *(9b)* Consonant [1] in the word /k'is a/.

Note: *9a* and *9b* are coi in the same scale.

Fig. 9 Broad-band spectrograms are shown to illustrate the shortening of [1] in cluster.

According to Klatt (1976) "the durational recording in clusters may have its origin in physical constraints on the speed of various articulators, their ability to act independently so that consonantal gestures partially overlap in time and on the articulatory distances to be traversed ". " Another possible cause of the shorting of consonants in clusters may be a desire on the part cf a talker to *maintain* a nearly constant duration for each word independent of its phonetic composition. It has been suggested that the shortening of initial syllables in polysyllabic words is also a result of this factor. However, it is hard to believe that constant word duration i; a very important constraint in English since duration has already been implicated as functioning to differentiate inherently long from short vowels, voiced from voiceless fricatives etc. " (Klatt, 1976).

6. Physiological Factors *:*

Finally the physiological efforts (to minimize the articulatory efforts) **have** been used to explain the difference in inherent phonological durations of vowels. For example the longer duration of low r vowels has been attributed to the extra effort to open the jaw in the context *0f* a consonant (Lindblom, 1967). Some of the physiological efforts arc already mentioned in the above paragraphs with relevance to the other factors.

Role of Duration in Speech Perception

The theory of segmental duration has some interesting implications for the way in which sentences are perceived *by the* listener. The segmental duration contributes to the perception of constituent structure and phrasal and lexical patterns. It serves as a cue to word boundaries (Klatt, 1974).

It has been proved that the listener, are particularly sensitive to the rhythmical aspects of sentence timing (Huggins 1972a). It appears that they are aware of an average speaking rate and adjust their durational criteria accordingly. Systematic changes in just notic able inferences, of about 20% or more may ssr\e as perceptual cues (Klatt, 1976), Because of the listener's internal representation of duration, the durational differences between the short and long vowels are perceived (Nocteboom, 1973)

It has been shown that duration is. a sufficient cue to change the identity of a fricative from voiceless to voiced (Cole and Cooper, 1975).

Klatt (1976) suggests that " the ma king of phrase-boundaries by increasing the duration of the phrase-final syllable can serve as a primary perceptical cue to the decoding of surface structure in spoken sentence ".

Emphasis is signalled by an increase in the segmental duration and change in the fundamental frequency (Klau, 1976).

Durational cues are capable of carrying considerable information in connected speech. The listeners may be aware *of* the durational rules. However, research is necessary on the type of ruler used be the listeners as cues in perception.

Contribution of Sanskrit Literature to the Durational Models

It is interesting to know that the ancient Sanskrit scholars had knowledge regarding the durational aspects and their importance. This is evident from the definition of phonetics as well as from ; he classification of speech sounds.

Tn the treatise Taittiriya UpaniSat, phonetics is defined as the study of speech sounds, their pitch, quantity, intensity, intonation and conjunction (T.U.II—29-32). Paniniya Siksa classified the speech sounds on the basis of various factors like the place cf articulation, etc., among which quantity is given the second place (P.S. 6-7).

According to quantity, speech sounds were divided into hrasva, dlrgha and pluta (P.&-8) (Short, long and prolated, which are 1, 2 and 3 matra long ;—unit of quantity ; respectively). They had set the units of quantity. The lowest unit was termed a paramanu which is considered to be equivalent to two Anus (V.R.P.§. 23). Next was a matra, the more commonly used unit, equivalent to 2 paramanus. It was compared to the time taken for the snap of a finger, eye blink or a flash of lightening (V.S. 27-3 ; N.S. 2—2-3 ; Y.S. 8).

Vowels were classified as short, long and prolated (P.S. 8) and consonants are considered to be half a matra long (V.R.P.S. 22; T.P. 1-38; S.Y.P.Y.S. I. 57). The intrinsic duration of consonants was also observed in the sense that the voiced sounds were considered to be shorter than the voiceless sounds (P.S. 20). The duration of nasalised sound when articulated in different places was considered different (L.S. 17).

It was noticed that the final syllable was prolated in calling someone at a distance, in reply to a greeting and in case of a doubt (Astadhyayr 8—2-83, 84, 97).

In Natyasastra, one of the oldest treatise in dramatics, the duratioal differences in different intonation patterns and the duration of pause are mentioned. It states that there exists a direct relationship between the duration of a pause and the length of the syllable. When pause is of greater duration, the syllable produced will always be long. However, the duration of the pause should not exceed 6 Kalas (a measure of time) (N.S. Chap. 15). The treatise suggests that actors should use (1) grave intonation and slow rate of speech in conditions of sickness, fever, hunger, communicating confidentially etc., (2) High, excited intonation and fast rate of speech in a rejoinder, confusion, harsh appoach, representing sharpness and roughness, agitation, challenging one who is not present, threatening etc. (N.S., Chap. 15).

It has been advocated that slow rate of speech should be used while teaching, medium rate while speaking and fast rate while reciting (P.S). The importance of duration was observed in considering the normalcy of speech which could be noticed by the fact that the durational deviations are included under articulation disorders (Rg. Veda Pratisakhya, Chap. 15).

Finally, the physical processes underlying the speech behaviour was also explored. Kaiyyata connects the perception of different rates of speech to a psycho-physical process affecting the nervous system. The ratio of slow to normal to fast rate of speech was considered to be 9 : 12 : 16. According to him, the ratio implied that 9, 12 and 16 drops of nervous fluid flow from the susumna (?) nerve of the listener, when he hears a sound in slow, normal and fast rate (Kaiyyata Pradipa 1—1-70).

Though the interpretation of the Sanskrit terms are difficult *(ex.* Susumna nerve), it would be useful to compile a detailed review of Sanskrit literature on duration of speech sounds, and to conduct research on the basis of this model.

Summary

It is known for a long time that duration is one of the important measurable aspects of ;peech. The study of duration is necessary to obtain knowledge about speech production and perception. Futher , the study of the factors affecting segmental durations and thedurational cues assisting the segmental perception are of importance to a speech language pathologist in order to understand the organization of the mental stuctures of language. The research is still in the infant stage and not much has been understoo speech production and perception. It might be expected thar further quantitative exploration on the segmental duration may lead to the formulation of the properties of the mechanism for the storage and timing in speech.

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Abbreviations used

L.Ś	Lomasa Ś iksa
N.Ś .	Narada Ś iksa
P.Ś	Paniniya Ś iksa
Ś .Y.P.	Suklayajus Pratisakliya
T.P.	Taittiriya Pratisakhya
T.U.	Taittiriya Upanisat
V.R.P.Ś	Varnaratna Pradipika Śiksi
V.Ś	Vyasa Siksa
Y.Ś	Yajnavalkya Ś iksa

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