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A Comparison of Stress and Syllable Isochrony

by

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Dedication

This thesis is dedicated to my parents, without whom this would not be possible, and to my wife, for her help and understanding.

Abstract

This study compares reading task data collected from ten English and ten French speakers to test the claims of stress and syllable isochrony. Examples of different foot sizes were selected from two texts and measured to investigate the effect of adding a syllable to the inter-stress interval. These durational data were tested by analysis of variance. The results are interpreted to show that, while the language groups are significantly different, these differences do not reflect the isochronic hypotheses. In their place, a "universal" timing system is posited which interacts with the language structure to give the observed timing phenomena.

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I. INTRODUCTION

In this thesis, I shall be looking at stress and syllable isochrony. These terms refer to types of speech timing which are hypothesized to be used by speakers of different languages. Isochrony means that certain sections of speech will occupy the same amount of time. In languages such as French, all the syllables are claimed to be of an equal duration, leading to the syllable being the main unit of timing in speech production. In contrast, languages such as English are claimed to use a constant inter-stress interval ([ISI] the duration between stressed syllables) regardless of the number of intervening syllables. The inter-stress interval is the duration from the beginning of one stressed syllable to the beginning of the next stressed syllable. In this sense it is similar to the foot, a unit commonly used in descriptions of poetic meter. While the foot can have the stressed syllable at either the beginning or the end, here, foot will be used in a stricter sense, as having the stressed syllable initially. Therefore, foot will refer to the hypothetical construct while inter-stress interval will refer to measured duration.

The concepts of stress- and syllable-timing have been considered for a long time. Over 200 years ago, Steele (1775) claimed that English was stress isochronous. However, it is only in more recent years that isochrony in the speech signal has moved to a position of greater importance. While theoretical works have divided isochrony into stress and syllable types, the studies based on experimental findings have not supported this. Although measurement data cannot tell the whole story, it is revealing that all the studies to date have shown, at best, a tendency towards stress- or syllable-timing, but always in relation to the specific language being studied. Therefore, it is difficult to determine what comprises a stress-timed language. Is it a language with equal intervals between stressed syllables, assuming equal to be defined on a psychophysical scale? Or is it a language whose inter-stress intervals fall within a statistically defined range of duration? These two criteria could allow different languages to comprise the group of stress-timed languages. As well, the same qualifications apply to syllable-timed languages. In this thesis, I shall be treating stress- and syllable-timing as being defined by the duration between stressed syllables or syllables, as appropriate. While a physical scale has the advantage of ease of comparison and measurement, we must not forget that any temporal interval should be measured in psychophysical terms, and is therefore liable to be transformed from its physical value. For this reason, we can only assign a duration to a section of speech, which must take into account such factors as the indifference interval, just noticeable difference limens and other perceptual phenomena involved in mapping a physical sound stimulus onto the sound as it is perceived In this way, we could obtain a temporal scale similar to the bark scale for loudness or the mel scale for pitch.

While we cannot claim to understand how a person perceives, we do have an increasingly clear picture of what is perceived. This allows us to predict more accurately whether two sounds will be heard as equal or not in duration. From this step, it is a short distance to determining if such concepts as stress- and syllable-timing are valid, or if they are artifacts of the perception of a differently structured language. It is interesting that most instrumental studies of stress- and syllable-timed languages have concluded that both show considerably more variation than could be ignored by the listener (Borzone de Manrique & Signorini, 1983; Crompton, 1980; Dauer, 1983; Delattre, 1966; Faure, Hirst & Chafcouloff, 1980; Nakatani, O'Connor & Aston, 1981). Unfortunately, only Dauer (1983) and Delattre (1966) have made a cross-language study. Delattre focused on syllable length while Dauer concluded that the languages he studied, whether supposedly stress- or syllable-timed, were the same in regard to their treatment of inter-stress intervals. This indicates there are no immediately recognizable acoustic cues in the speech signal that trigger our recognition of the perceived timing patterns in these two groups of languages.

The question of speech timing has long intrigued people. By necessity, all utterances are time dependent. As well, differences of timing can be used to make contrasts, such as single versus geminate consonants. A language user, in order to communicate effectively, must control the timing of speech so that it matches the listener's expectations (Huggins, 1978). Speakers manipulate timing relations in order to make phonological distinctions and to delineate syntactically motivated differences. On a universal level, some changes in speech timing come about due to physiological limitations and interconnections of the human articulatory system. As well, speech is limited by the ability of the vocal tract and speech appartaus to produce and the auditory system and brain to perceive acoustic signals. With all of these levels interacting, understanding which variations in timing are due to "universal" constraints and which to language-specific rules is a complicated task, especially as the realization of speech timing is always an inextricably linked function of these universal and language-specific factors.

Presumably, this complexity accounts for speech timing over stretches of speech larger than a segment or a syllable having been largely unstudied. At a segmental level, differences in timing between languages can only be attributed to rules governing the implementation of segments, given the basic assumption that all humans are equipped with equivalent articulatory and nervous system apparatus. Also, language structure is unimportant at this level, except for determining the phonetic inventory of the language to be accounted for, as percentages of occurrence are irrelevant. The syllabic level interacts with language structure to a greater degree, as is evidenced by constraints on possible syllable structure in different languages. Here again, the effect of language structure is small, because the amount of speech covered by one syllable is minimal in relation to a fluent conversation. Even so, languages do not seem to be equivalent in their treatment of different syllables (Delattre, 1966).

When syllables are grouped into utterances, languages begin to show their individual characters. The cumulative effects of segment inventory, syllable structure and phonetic constraints lend each language a distinctive sound and, perhaps, rhythm. Is it possible to conclude that timing relations in languages are not different because of syllable and stress isochrony but because of other factors? This question is central to my thesis. I shall show why a theory which does not block languages into an a priori grouping of stress-timed and syllable-timed (and mora-timed as well) is to be preferred. This allows us to look at the data obtained in a new light, as well as to avoid imposing a pre-conceived notion on the essentially unstudied phenomenon of inter-stress timing.

Some researchers have sought to explain parts of our internal control of speech timing. Kozhevnikov & Chistovich (1965) based their concepts on the recorded output of several Russian speakers. From their data, they argued that the comb model, with the stressed syllables coming at a pre-determined time, fit the data better than the chain model, which depended on the feedback of information about the successful completion of the previous movement. Ohala (1975), however, found evidence that both these models were important in speech timing, with "...the chain model for long-term timing, the comb model for short-term timing." [1] Lenneberg (1967) looked at speech rate by measuring the syllable rate of three radio newscasters speaking American English, as well as studying evidence from several other sources, such as delayed auditory feedback and neurological rhythms. The collected data pointed to a rate of six syllables per second.

One problem is that the above explanations do not have any necessary bearing on the question of stress and syllable isochronicity. If anything, the only clear interpretation of all three views is that languages share a common timing base. For example, Lenneberg (1967) based his claims on perceptual factors, as well as language output, while Ohala (1975) used an American English and a Japanese speaker to demonstrate his claims. Since these explanations do not address the issue of isochronicity directly, I shall not be dealing with them further.

For this study, I collected data from native speakers of French and English, then measured the inter-stress intervals, to see if the resulting measurements supported the hypotheses of stress and syllable isochrony. If these descriptions of speech timing are accurate, English speakers

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[1] Ohala (1975), p.452.

will use a constant inter-stress interval for all the feet and the French speakers will have a constant syllable length across all the feet.

I shall show that, while speakers of English and French are significantly different in their treatment of the inter-stress interval, these differences do not show the results predicted by isochrony. For example, if the inter-stress interval were to stay constant for English speakers while syllable duration were constant for French speakers, the difference in duration between English and French speakers would be a function of the number of syllables measured. That this is not the case suggests that stress- and syllable-timing are incorrect. An approach which better suits the data collected, as well as being supported by the three theories mentioned directly above, is a "universal" timing hypothesis. The obvious differences between languages, both physically and psychophysically, can then be attributed to their individual structure instead of an underlying timing pattern.

II. LITERATURE REVIEW

The review of the literature is arranged chronologically, due to the lack of any other simple organizational scheme. All works by an author are placed under the earliest contribution reviewed.

A. 1965 to 1969

Delattre (1966) investigated the range of syllable lengths in English, French, German and Spanish and found that these languages differed in their ratio of longest to shortest syllable and the durational differences between them. The durational difference between the shorter, unstressed, non-final, open syllables and longer, stressed, final, closed syllables was 204 msec. for French (the smallest) and 287 msec. for English (the greatest). This shows that the languages do give some support to the hypothesis of stress and syllable isochronicity, as English shows a greater tendency to compress syllable duration, while French maintains a more constant length. On the other hand, it also indicates that syllable duration in French varies almost as much as it does in English. Since the average syllable duration was 229 and 242 msec. respectively, these divergences would be perceivable (Lehiste, 1977). Another point was that only French relied on duration for the perception of stress, while the other three languages required intensity variation as well. That Delattre was considering stress, and not emphasis, is clarified by his statement that, in French, stressed syllables were always final in the sense group and final syllables were always stressed. Although this study used extemporaneous speech by the subjects, it is unfortunate that we are not told how many subjects participated, nor on what topic(s) they spoke.

Allen (1968) was one of the first to look at the commonly assumed description of stress-timing in English.

> Since we already know that the stresses of English are produced by muscles that probably move rhythmically and are perceived by listeners who are all too ready to hear rhythms, an acceptable description of English speech rhythm must now tell us more than that "the stresses of English tend to be regularly spaced in time." [2]

He also pointed out that the three most important influences on inter-stress intervals are speech tempo, phonetic composition and prosodic contour. Allen (1975) took these concepts a step further viewing speech rhythm as an exemplar of motor rhythms and behaviour and noting that people generally act rhythmically, with those rhythms averaging two beats per second. Of these rhythmic acts, the most common involve either successions or alternations. Because English speakers "reduce" unstressed vowels in both quality and quantity, differentiating them from stressed syllables, they can be viewed as using alternation. French speakers use succession, because all syllables are given an "unreduced" vowel. Also, he claimed that loudness, pitch and duration affect the perceived rhythm of noise stimuli in an

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[2] Allen (1968), p.268.

interactive fashion. Louder or higher-pitched tones are heard as leading the perceived grouping, while tones of longer duration are heard as following the group. Allen & Hawkins (1978) looked at the problem of how a child learning English could change from its initial syllable-timed rhythm to the adult "ideal" of stress timing. They found that a child generally produces only syllables with a "full articulation" ([+heavy] Vanderslice & Ladefoged, 1972) at first, i.e. those with an unreduced vowel. Some of these give way to syllables with "reduced timing" ([-heavy]) as the child becomes more proficient. Therefore, they concluded that the child initially displays the effects of universal constraints, becoming more and more influenced by the language it is learning.

Nooteboom & Eggermont (1969) recorded one Dutch speaker reading a text. Their analysis of these data indicated that if Dutch uses stress-timing, it is neither clear nor straightforward, since they found the relationship between the inter-stress interval and number of unstressed syllables to be linear. Nooteboom (1972) found vowel onset to be the probable focus of rhythmical judgements. Nooteboom, Eggermont, 't Hart, van Katwijk & Slis (1974) judged the vowel onsets of stressed vowels to be the most likely candidates for a primary cue for speech timing for the perceptual system, as they are relatively independent of context and give information on speech timing. However they also admitted the possibility of using the vowel onset of every syllable.

B. 1970 to 1974

Lehiste (1970) argued that speech timing must be at least partially controllable in order to be used as a distinctive feature, e.g. between long and short vowels. Also, she pointed out that English, in common with some other languages, shortens unstressed syllables more than stressed syllables as speech rate increases. It seems that this could be consistent with the stress-timing hypothesis, but presents serious trouble for a syllable-timed language, as the syllables would not be able to maintain their one-to-one durational relationship. Lehiste (1977) attempted to reconcile the data gathered in experimental studies with the hypothetical construct of stress isochrony by appealing to an interaction between the production and perception systems. If both systems share a tendency towards isochrony, then even sentences which are objectively non-isochronous could be perceived as isochronous. One question which is not looked at is whether the same mechanisms could be used to explain syllable isochronicity. If so, then how do children "tune" these tendencies in to the correct unit? If not, why do French speakers not use stress-timing as do English speakers? Lehiste (1979) looked at the accuracy with which listeners could judge the duration of four noise-filled intervals. Assuming the accuracy of perception of duration is less when dealing with language, she found the results indicated that listeners could easily perceive English to be stress isochronic, as a change of greater than 100 msec. was necessary to cue accurate judgements of the longest interval.

Uldall (1971,1978) used data from one subject reading a text at normal and fast rates. The inter-stress intervals were measured and the results were interpreted as indicating a tendency towards stress isochrony in English. 57% of the filled feet (those not containing a "silent" stress) had a duration between 385 and 520 msec. in the normal reading. However, if speech is treated as a rhythmic activity with an average cycle of 500 msec. (Allen, 1975), these data indicate that the average duration of filled feet at a normal speaking rate is 520 msec. While this may be coincidental, it also matches well with other collected data that we shall be looking at. Also, it explains why inter-stress intervals with a larger number of unstressed syllables, such as four or five, can be of a longer duration without affecting judgements of isochronicity. Uldall suggested that these inter-stress intervals (or feet) are counted as two feet, but without specifying how this could be achieved by a listener.

Grosjean & Deschamps (1972) looked at recorded spontaneous radio interviews with French subjects. They found speech rate to be very stable at 5.21 syllables per second with 82% between 4.4 and 6.0 syllables per second. However, one of their concerns was to explain why the speech rate was higher among the French subjects than among two groups of English subjects (Goldman-Eisler, 1968; Grosjean, 1972). They determined that it was due to the number of pauses and/or length of breath groups rather than a difference in speed of articulation. They did not consider extra-linguistic factors. The French subjects were interviewed on radio about their area of expertise. In Goldman-Eisler (1968), the subjects were asked to describe and interpret cartoons. Grosjean (1972) used subjects with English as a second language. Grosjean & Deschamps (1973) extended this study by looking at French and English speakers in a similar situation. This time, they found the two languages to be nearly identical in speech rate, as well as in the ratio of articulation time (total speech time minus pause time) to total speech time. Even so, they found the length of the breath groups, i.e. the number of words between two pauses, to be different: English 4.67 words per pause, French 6.22 words per pause. However, the English subjects used shorter pauses, which compensated for this difference. Grosjean & Deschamps (1975) made a more direct comparison between English and French by using a similar corpus for each, namely radio interviews on the subjects' main centres of interest. They again found the languages to have nearly identical speech rates (English: 255 syllables per minute, French: 264 syllables per minute), ratio of articulation time to speech time (English: 83%, French: 84%) and articulation rate (English: 5 syllables per second, French: 5.21 syllables per second). There was a difference in the length of breath groups (English: 9.5 syllables per group, French: 12 syllables per group), which was attributed to a greater number of pauses within the verb phrase among English speakers.

C. 1975 to 1979

Bertinetto (1977) had two subjects repeat a group of fifteen sentences and the last six lines of Dante's "Divina Commedia" in order to collect some data in Italian, which is hypothesized to be a syllable-timed language like French. He listed four properties which can be used to differentiate stress- and syllable-timed languages:

1. stress-timed reduce non-stressed syllables,
2. stress-timed reduce the duration of unstressed syllables more than stressed syllables as speech rate increases,
3. stress-timed have a less definite syllabification, and
4. stress-timed allow a greater elasticity in the placement of accent.

Analysing the results, he found that only feet with a roughly equal number of syllables had an equal duration. As well, when rate was increased, the last foot of the sentence was found to compress less than the other feet. Although both of these results argued against labelling Italian as a syllable-timed language, Bertinetto still claimed

> ...possiamo concludere che gli informatori utilizzati nel suo esperimento hanno mostrato per tutti i piedi ritmici, qualunque fosse la loro posizione sequenziale, una netta tendenza versa l'isocronismo. [3]

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[3] Bertinetto (1977), p.87. ... we can conclude that the

He finished by claiming that, in stress-timed languages, only the stressed syllables can be definitely fixed in time, leading to isochronism in the rhythmic feet, while syllable-timed languages allow each syllable to retain its "forte tensione", giving the syllable as the primary element of the rhythmical structure. Although this does not help us to understand why inter-stress intervals of perceptually different lengths can be regarded as equal by listeners, it does indicate why these two prototypes have been put forward for consideration. It does not clarify why they are still prevalent after having been reduced to the status of tendencies.

Fowler (1977) addressed the view that timing is an extrinsic quality in speech planning, with a timeless plan being realized by a timing program. Another question is that if, as usually developed, stress-timing refers to a tendency, to what extent must this tendency be present before it is the major factor? Fowler suggested that the speech plan must contain a four-dimensional description and not leave the temporal dimension to an outside function. Therefore, the central issue is how to reduce the degrees of freedom inherent in a plan which specifies all the dimensions required for the speech act. For this task, she put forward coordinative structures, groups of muscles activated as a single unit by the central control. This view

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[3](cont'd) informants used in this experiment showed for all the rhythmic feet, whatever their sequential position, a definite tendency towards isochronism. [TCR]

is preferred because:

1. it reduces the degrees of freedom,
2. it reduces the descriptive power by not allowing possible but non-occurring movements,
3. it uses "prefabricated functional groupings of muscles" [4], and
4. it allows the central command and the movement to not be in a one-to-one relationship.

This is then coordinated with the concept that vowels and consonants are produced by different but partially overlapping muscle groups with a continuous production of vowels and an overlay of consonants. In this way, stress-timing may result from the perceptual detection of "the period of the superordinate coordinative structure governing vowel production." [5] This period could then be related to using a fixed amount of "articulatory effort" per stressed vowel. Fowler & Tassinary (1981) argued that the lack of stress isochrony in speech that has been analysed is due to incorrect measurement techniques, not a lack of isochrony. They used three subjects speaking nonsense syllables freely, as well as in time to a metronome. In the metronome-timed speech, they found vowel offsets to be the most nearly stress isochronous portion of the acoustic signal, while the metronome pulse did not coincide with any acoustic segment boundary. From this, they claimed that vowel offsets are regulated to be isochronous, while vowel onsets are not, and that, while this does not show the vowel offsets to be the timed section, they are an easily identified one. However, from their data, it appears that

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[4] Fowler (1977), p.116.
[5] Ibid, p.151.

the two syllables which gave the greatest amount of deviation for the vowel onset in relation to the metronome pulse are /str/ and /tr/. It is interesting that the measurement of /r/ or vowel duration is more complicated in this circumstance, as the point at which the waveform changes is not obvious. If we then delete these syllables from consideration, there is little to choose between the vowel onset and offset as regulators of speech timing. Fowler (1982) studied how the perception of isochrony can arise from a non-isochronous signal. One of her conclusions is "...that perceived timing of stressed syllables is a function only (or primarily) of perceived information pertaining to vowel identity..." [4] and, therefore, that stress isochrony results from acoustic information on the timing of stressed vowels. To this is added a caution that listeners may use different measures than the conventional linguistic ones to determine speech timing. Tuller & Fowler (1980) looked for isochronous articulatory gestures underlying perceptually isochronous utterances. They had six subjects repeat either one nonsense syllable forty times or a sequence of two nonsense syllables twenty times while recording the speech wave and orbicularis oris activity. The subjects were instructed to use equal stress on all syllables and talk isochronically. Their conclusion was that "... when asked to produce isochronous monosyllabic utterances, talkers comply by producing isochronous

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[4] Fowler (1982), p.25.

articulatory gestures." [7] While this could lead to the conclusion that listeners have access to articulatory information, it is not the only possible interpretation. Tuller & Fowler (1981) used infinitely peak-clipped stimuli, in order to equalize their intensity, with no effect on the subjects' judgements of stress isochronicity. Therefore, amplitude is not an important variable in the perception of stress isochronicity. That is, as long as all stimuli are of a sufficient amplitude to be audible.

D. 1980 to 1983

Crompton (1980) looked at French timing, in order to determine what the important factors are governing syllable length, other than segmental composition. Defining "nucleus" as the last fully accented syllable in a tone group (i.e. a group of syllables in one tone contour), he found that nuclear syllables are longer than non-nuclear syllables and that nuclear syllables before a clause boundary are longer than before a sentence boundary which are longer than before a phrase boundary. Also, he showed initial syllables to be shorter than non-peripheral (i.e. medial), non-prenuclear syllables. As these variations range from 65% to 180% of the "inherent syllable length", they should be perceivable. This helps to indicate that syllable-timing for French is no simpler an hypothesis than is stress-timing for English. Interestingly, he found no consistent durational effect of

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[7] Tuller & Fowler (1980), p.281.

accent on the syllable, although some subjects did show a slight increase of about 5 msec.

Faure, Hirst & Chafcouloff (1980) recorded two subjects reading lists of sentences and then had three phoneticians mark the stressed syllables and pauses to determine the inter-stress interval in English when reading. Their data showed the inter-stress interval to range between 0.14 and 1.26 seconds. However, the means of the different sized feet showed a likely prospect to be that stressed syllables averaged 220 msec. while unstressed syllables averaged 140 msec. In spite of the definite linear increase found, they still claimed

> It is the recognition of a pattern of recurrent stressed syllables against a background of unstressed syllables that accounts for the fact that widely different intervals between stressed syllables appear to the listener to be "approximately" equal. [8]

Although no support is given for this statement, it accounts for their view of English as stress isochronic.

Balasubramanian (1980) took data from Tamil and compared them with both the syllable- and stress-timing hypotheses. Tamil is not stress-timed as "...the time taken to utter a foot seems to be almost proportionate to the number of syllables in a foot." [9] Alternatively, syllable-timing also seems unlikely, because syllable duration varied from 30 to 417 msec. in a sample of 197 syllables. He then suggested a hierarchy of syllable

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[8] Faure, Hirst & Chafcouloff (1980), p.77.
[9] Balasubramanian (1980), p.457.

structure based on an interaction between short or long vowels and open or closed syllables in order to account for the observed data.

Major (1981) studied Brazilian Portuguese to determine if it is a stress-timed language. He concluded that the language is in the process of shifting from syllable- to stress-timing. He collected data from subjects in citation, normal and casual speech. Then, under the assumption that citation speech is the most conservative style and casual speech the most innovative, he found the casual speech to be more typical of stress-timing. This was due to the general lack of shortening processes in citation speech, while, in casual speech, even whole syllables were omitted.

Nakatani, O'Connor & Aston (1981) looked at English speech rhythm by using reiterant speech, substitution of the syllable 'ma' for every syllable in a noun phrase, in order to eliminate variation of syllable composition while retaining the prosodic features associated with normal speech. Unfortunately, this also required them to use selected, trained subjects who could accurately reproduce a phrase reiterantly. Then, of the recorded tokens, only those judged to be acceptable versions were analyzed. Their data indicated that the inter-stress interval increased in direct proportion to the number of unstressed syllables included, i.e. that English is actually syllable-timed.

> The study confirmed the importance of the following factors as determiners of syllable duration in American English:
> 1. the level of stress on a syllable

2. the presence of a word or phrase boundary following a syllable.[10]

Not suprisingly, they found no evidence that English uses stress isochrony.

Roach (1982) compared one speaker in each of three syllable-timed languages (French, Telugu, Yoruba) and three stress-timed languages (English, Russian, Arabic) listed as examples by Abercrombie (1967). Spontaneous recorded speech was marked for stress and the syllable and inter-stress interval durations were measured. The standard deviation in syllable length, the variance of the percentage deviation of inter-stress interval and the percentage deviation correlation to number of unstressed syllables in the inter-stress interval showed no evidence that the six speakers could be grouped according to their languages' timing pattern. Roach concluded that all languages and all speakers use both stress and syllable timing, although one type might predominate in a given language.

Wenk & Wioland (1982) not only found no evidence that French is syllable-timed, but they inveighed against the very concept of syllable timing.

> It is indeed possible to draw the most unflattering of conclusions for the French language from the assumption that French is "syllable-timed".
> (i) To say that French syllables are of relatively equal length is, by implication, to deny the existence of accented syllables in the language.
> (ii) To say that French has no accented syllables is to deny the existence of rhythm in the phonetics of the language, since

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[10] Nakatani, O'Connor & Aston (1981), p.101.

without accents rhythm is virtually unconceivable.

(iii) Since, "like other motor behaviors, speech is compelled, by natural constraints on the relative timing of components, to be rhythmic" (Studdert-Kennedy, 1979 p.61), to deny the rhythmical organization of French is to imply that French is not fully a language. [11]

While this ignored the possibility that accent on syllables can be signalled by other means than duration, it does indicate their feeling towards syllable-timing. They suggested that each language has a regulator: "...that abstract rhythmic unit which determines the limits of rhythmic groups." [12] English has leader-timing, or a unit-initial regulator, while French uses trailer-timing, a group-final regulator. In this respect, Allen (1975) supports their claim by pointing out that a louder or higher-pitched stimulus will lead the perceived rhythmic grouping while a longer stimulus will follow the perceived grouping. As English stressed syllables are marked by pitch, amplitude and duration while French are only marked by duration (Delattre, 1966), this would explain why the two languages have a differently perceived regulator placement. The regulator is combined with the build up, occurrence and release of accent to give rhythm. They also put forward six principles which help to determine how speech rhythm is produced. For our purposes, the most important of these are the rhythmic discharge principle: "...the tendency to maintain a pre-established rhythm will influence a speaker

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[11] Wenk & Wioland (1982), p.203.

[12] Ibid, p.204.

to produce successive groups of equal or nearly equal syllable count." [13] and the least syllable principle: speakers will produce small rhythmic groups.

Borzone de Manrique & Signorini (1983) studied Argentine Spanish, another language claimed to be syllable-timed. However, they found the duration ratio of stressed, non-prepausal, open syllables to unstressed, non-prepausal, open syllables to be 1.4, which is not syllable isochronic, but is beyond the just noticeable difference limen for detection of durational differences. In fact, they concluded that their data indicated Spanish has a tendency towards stress-timing. They also found stress to be associated with higher pitch, longer duration and, on occasion, greater amplitude.

Dauer (1983) compared English, Spanish, Italian and Greek speakers, and also incorporated data from other sources to also include Japanese, French and Portuguese. He found that, in all these languages, 75% of the inter-stress intervals were between 0.3 and 0.7 seconds. Also, an additional unstressed syllable added 110 msec. to the inter-stress interval in all of them. In fact, the main cause of variation was due to slow versus fast talkers. English was shown to be no more regular in inter-stress interval duration than the other languages. "Rather, what these data reflect appears to be universal properties of temporal organization in language." [14] If all these

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[13] Ibid, p.206.
[14] Dauer (1983), p.54.

languages use the same durational organization, the question is what gives their perceived rhythms such variation? Dauer suggested that this is due to language structure, not only in terms of possible syllable and segment combinations, but in syllable duration and number of unstressed syllables in an inter-stress interval as well. As examples, he suggests that stress-timed languages have a greater variation in syllable duration, mostly due to an enhanced repertoire of syllable types. Another suggestion is that, in stress-timed languages, syllable structure and stress are mutually reinforcing, with heavy syllables being stressed more frequently than light syllables. Dauer defined heavy syllables as those containing many segments and light syllables as those with few segments. Also, stress-timed languages use centralized vowels in unstressed syllables, but do not delete them. Syllable-timed languages can eliminate shorter syllables and do not use centralized vowels, although consonants can be affected or eliminated. Lastly, the greater the effects of stress on a language, the more likely it is to be considered a stress-timed language. "It is precisely the language structure with all its language specific segmental variation that is responsible for perceived differences in language rhythm." [15] Therefore, Dauer recommended using a continuum of "stress-based" to rank languages which would imply nothing about their timing, yet help to explain their perceived rhythm.

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[15] Ibid, p.59.

III. METHODS

This study was designed to investigate evidence from native speakers engaged in a reading task. The inter-stress interval was chosen as the measurement of interest. Two hypotheses were advanced: English speakers use a constant ISI and French speakers use a constant syllable duration, no matter the size of the rhythmic foot.

A. Subjects

Ten native speakers of French and English were recorded, seven women and three men for English, six women and four men for French. Of the English speakers, nine were native Canadian speakers, while one came from the north-western U.S. The average age was 29.7 years, and all had graduated from university. Three reported very slight impairment of hearing, and one had suffered from a speech defect, although at a young age. The French speakers were six native Canadians, three French and one Belgian. The average age was 31 years. Seven were university graduates, two were high-school graduates and one had graduated from college. None of them reported any speech or hearing impairment.

B. Materials

Each subject read two texts. One, from Reader's Digest/Selection, concerned a conversation on a train. The other described the technique of aerial firefighting. (See

Appendix A.) These texts had been translated by the publisher, the former from English into French and the latter from French into English. They were chosen to exemplify narrative with dialogue and descriptive styles of speech, allowing the study to look at more than one register. Both texts were independently marked for stress locations by two linguists. The only sections used for the analysis were those in which all stress markings were in agreement. However, the agreement about stress placement was very high. In marking, only two degrees of stress were used, as it has been claimed that listeners cannot reliably differentiate more than this (Nakatani et al., 1981). The stress markings indicated the limits of the rhythmic feet, which run from the beginning of one stressed syllable to the beginning of the following stressed syllable. From the marked texts, all of the rhythmic feet which did not cross a noun phrase - verb phrase, clause or sentence boundary were noted. Then, six samples were selected for each foot size, taking three from each text. However, in the case of foot 5 in both English and French, four samples were selected from the firefighting text and two from the train text. This was due to a lack of samples with suitable segmental composition. Foot 6 type was not included in any of the statistical analyses as only one English and two French examples were found. No attempt was made to try to represent the percentage of each foot occurring in actual language, as this would require either a very small number of foot 5 or a large number of foot 2 and 3 to be analysed.

The samples were chosen on the basis of the ease of segmenting the acoustic signal. Therefore, those with a greater number of stops and fricatives were preferred. The main criterion was that each stressed vowel had to be preceded by a consonant which would allow a precise indication of the vowel onset. If this criterion was met, then the samples which gave the greatest number of clear-cut vowel onsets for the intervening unstressed vowels, if any, were used. For all of the foot types analysed, this allowed a somewhat random choice to be made, as there were more than six samples available which met the requirements.

C. Apparatus

Microphone: Sennheiser MD 421N

frequency response: 30-17,000 Hz ±5dB

sensitivity: 0.2 mv/microbar at 1000 Hz

directionality: cardioid

Tape recorder: TEAC A7030 GSL

frequency response: 50-15,000 Hz ±2dB

speed: 15 ips

S/N ratio: 58dB

Audio frequency filter: Rockland Programmable Dual Hi/Lo filter, series 1520

frequency range: 0.001 Hz - 111 kHz

accuracy: ±2% of dial setting

Minicomputer: DEC PDP 12/A

memory: 16 kbits

operating system: OS/8 and Alligator.

D. Recording

Subjects were recorded individually in a sound treated recording room. The only instruction given was to read the texts in a normal conversational style. Subjects were given the texts before the recording and asked to read them over, so they would be familiar with them and have an opportunity to clear up any uncertainty before the recording. The order of reading was counterbalanced. Any questions about the experiment itself were answered after the reading. At that time, information about the subject was also collected, in order to control for any inconsistencies in the data which might be found.

E. Sampling

The stimuli were bandpass filtered (68-6800 Hz) in order to eliminate any 60 Hz hum. The upper limit was used to prevent aliasing due to sampling at 16 kHz. The amplitude of each portion of speech was calibrated to provide the maximum signal level without peak clipping. Following this, the signal was digitized at a 16 kHz sampling rate on a PDP 12A minicomputer, using the Alligator operating system

(Stevenson & Stephens, 1978), and stored in the computer memory. A program, written by A. J. Opperthauser, was used to allow sampling of 60 seconds of speech at one time (see Appendix B).

F. Measurement

The signal was displayed in 1.6 second sections by the program shown in Appendix B. This amount of time was sufficient to include the entire rhythmic foot being measured in almost all cases; the only exceptions were those with a great amount of pause time. The program gave a visual display of the acoustic waveform, and allowed auditory playback of the whole section or any part of it as well. Therefore, visual and auditory identification of the recorded signal could be used to clarify the probable boundary location when necessary during segmentation.

In order to measure the duration of a desired section, the computer's cursors were positioned so as to delimit it. Then, the signal bounded by the cursors was extracted, labelled and automatically measured and the duration printed on the teletype. Positioning the cursors involved some arbitrary placement, e.g. when a vowel was beside a liquid. It was in these cases that the auditory playback of the section enclosed by the cursors was extremely useful, as the gradual change of the waveform from that of the preceding to the following segment was visually indistinct.

For the purposes of this study, foot, or inter-stress interval, was defined to include the duration from the start of the initial stressed vowel to the start of the final stressed vowel. This choice made the feet easier to identify from the acoustic waveform and is also supported by several studies linking people's rhythmic judgements to vowel onset (Nooteboom, 1972; Nooteboom et al., 1974). The feet were categorized according to the total number of syllables they contained, e.g. foot 1 includes only the stressed syllable, foot 2 has one stressed and one unstressed syllable and so on. The ISI duration was broken down into vowel (V), consonant (C1) and pause components. ISI1 is the total duration for the foot, while ISI2 is the foot duration minus the pause time. Further, the consonant and pause times can be grouped together to give the inter-vowel interval, i.e. the foot duration not taken up by the vowel(s). This aggregate is termed C2. Therefore, ISI1 duration equals the total of the V and C2 times, and ISI2 equals the durations of V plus C1.

The duration of the stressed vowel (StV) and the first unstressed vowel in the foot (1UstV), if any, were analyzed to compare the effects of compression as the foot size grows. Stress isochrony and syllable isochrony make very different predictions about the effect on these parts as foot size increases.

To measure the ISI duration, the first cursor was positioned so as to intersect the displayed signal at the zero crossing where the first stressed vowel of the foot began to dominate the waveform. The second cursor was positioned at the same place in relation to the following vowel, i.e. the next stressed vowel for foot 1 and the following unstressed vowel for all other feet. This duration was measured. Then, the first cursor was moved to the zero crossing where the consonant following the stressed vowel began to dominate. After this duration was measured, the first cursor was brought up to the position of the second cursor and the second cursor was moved to the end of the next vowel. The pattern was then repeated as many times as necessary to measure the duration up to the beginning of the following stressed vowel. (For a visual example, see Krishnan (1983), Figure 3, page 29.)

In the measurement of ISI, only pause time evident in listening to the recorded passages was measured, roughly that greater than 30 to 40 msec. Extra measurements were made to give separate durations for the C or V portion on either side of the pause, as well as the pause duration itself.

To calculate the duration of ISI1, the measurements from vowel to vowel were summed. ISI2 is equal to ISI1 minus the measured pause time, if any. V duration is given by ISI1 duration minus the consonant and pause time (C2). C1 duration is equal to C2 minus the pause time. The duration of StV and 1UstV were calculated by subtracting the consonant duration from the appropriate vowel to vowel duration. The measured durations for each subject are listed in Appendix C. The rows comprise the six tokens chosen for each foot. Each subject's data are grouped. For ISI1, ISI2, V, C1, C2 and StV, each subject takes five lines, from foot 1 to foot 5. For 1UstV, each subject has only four lines, from foot 2 to foot 5.

IV. DATA ANALYSIS

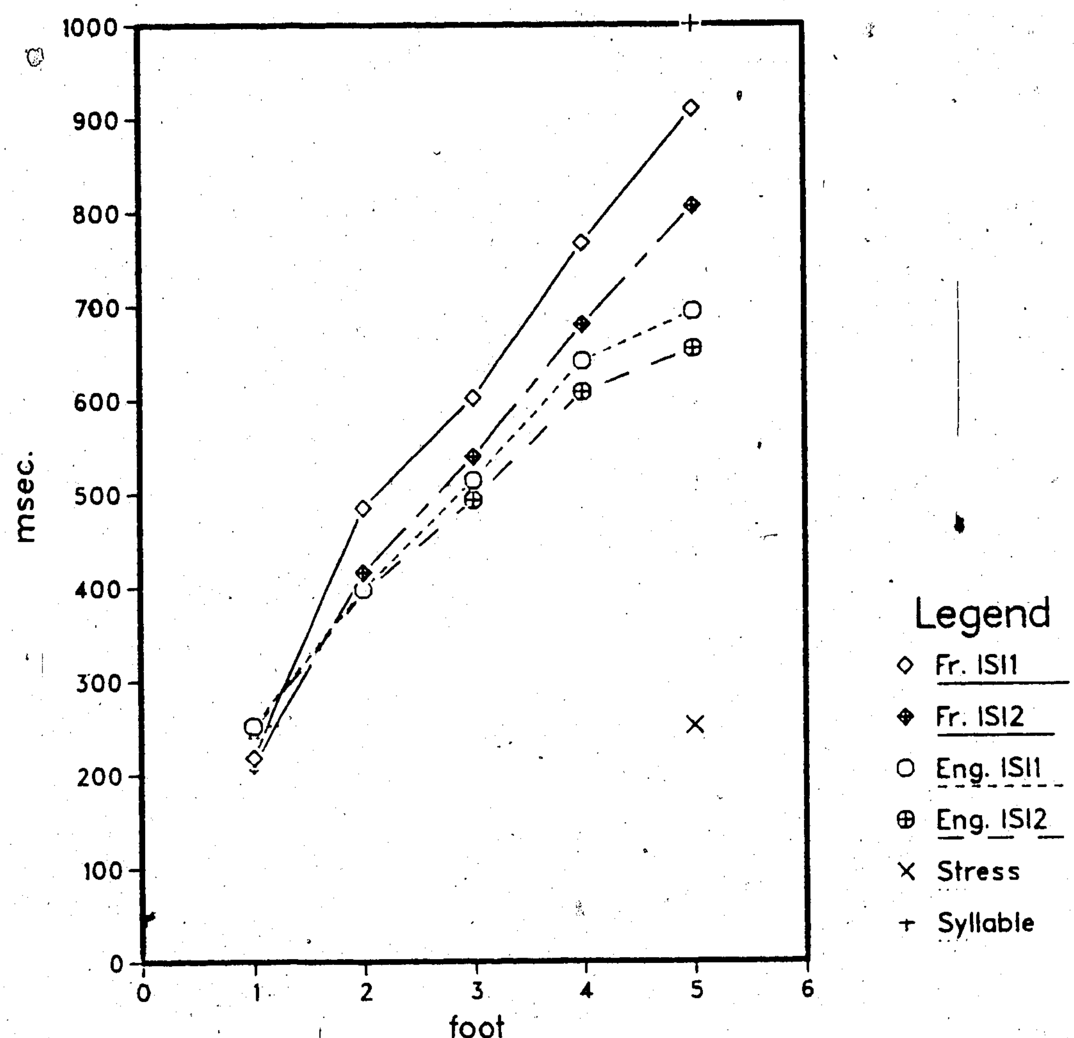
An analysis of variance (ANOVA) was run on seven of the measured durations. The total duration of the inter-stress interval, including any pauses and/or repetition by the subject, was termed ISI1. As a comparison to this, the inter-stress interval with pause and/or repetition deleted (ISI2) was also calculated. The duration of all the vowel segments (V) automatically excluded pause time, due to the measurement technique. For the consonant duration, the consonant minus pause time (C1) and consonant plus pause time (C2) were treated separately. The final two analyses were on the stressed vowel duration (StV) and the first unstressed vowel (1UstV) after the stressed vowel.

For each ANOVA, the same factors are involved. The first is language (L), with two levels, English and French. The next is foot size (F), with five levels (only four for 1UstV). Subjects (S) are the next, with ten for each language. The last is token (T), with six for each foot type. For all analyses, language and feet were the fixed factors and subjects and tokens were the random.

A. Inter-stress Interval 1 and 2 (ISI1 and ISI2)

The deletion of pauses and/or repetitions from the inter-stress intervals had no effect on the significance of the results. Although the means for the two languages become more similar, the level of significance actually drops by a slight amount. This indicates that the pause time, which was

Figure 1 — Inter-Stress Interval



SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	180195552.	1	180195552.	745.07	0.0000
L	S(L)	1400893.	1	1400893.	5.79	0.0270
F	SF(L)	23776326.	4	5944082.	178.91	0.0000
S(L)	T(LSF)	4353285.	18	241849.	7.16	0.0
LF	SF(L)	974527.	4	243632.	7.33	0.0001
SF(L)	T(LSF)	2392086.	72	33223.	0.98	0.5184
T(LSF)		16882952.	500	33766.		

Table 1: ANOVA Summary for Inter-stress Interval 1

a considerable amount for some subjects, did not affect the interpretation of the results. Because speech happens in real time, it seems unlikely that the extra duration introduced by pauses can be excluded by the listener. For this reason, I believe that the analysis which includes the pause time is a more accurate reflection of how people talk and perceive. For example, Klatt (1976) claims that pause time makes up 50% of the duration of a conversation and 20% of a fluent reading. It is therefore encouraging that the statistical analysis is, to all intents, not changed by using the observed data, rather than the edited measurements. There are changes in the measurements themselves, which indicate quite straightforward results. The pauses are more frequent in and add more duration to the longer feet; the differences are foot 1: 5.9 msec., foot 2: 36.0 msec., foot 3: 42.1 msec., foot 4: 60.0 msec., foot 5: 71.7 msec. Some subjects paused much more frequently and/or for longer periods than others. The range, collapsed across inter-stress intervals, is from 0.0 to 224.3 msec. Another change, which confirmed my suspicions when listening to the tapes, is that the French speakers produced more pause time than the English speakers. Their respective pause times were: French - 66.21 msec., English - 20.13 msec. However, the two ISI measures are significant at the same level of probability in comparing English to French.

Thus, both ISI1 and ISI2 indicate that English and French are not drawn from the same timing group. Looking at the LxF interaction, ISI1 shows $F = 7.33$, d.f. = 4, $p < 0.0001$, while ISI2 gives $F = 28.04$, d.f. = 4, $p < 0.0000$. This indicates that pause time connected with a reading task appears to be statistically unimportant except as it affects the total duration. Otherwise, it would appear to be randomly dispersed both among subjects and tokens, except that longer inter-stress intervals offer a greater opportunity for disruption by pauses due to their greater extension in time. It is possible that this disruption is actually due to the limitations of working memory, so that as the number of syllables involved in an inter-stress interval approaches the magic number of 7±2 (Miller, 1956), pauses become more frequent because the processing system finds it increasingly difficult to encompass the whole interval in one unit. This, however, assumes that the inter-stress intervals are handled as separate syllables, each of which composes a unit in speech production. Even if words are used, it is still obvious that a longer inter-stress interval, on average, will contain a larger number of words. There is always the possibility that

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	152925123.	1	152925123.2	2366.65	0.0000
L	S(L)	383498.	1	383497.6	5.93	0.0255
F	SF(L)	18734023.	4	4683505.7	887.80	0.0000
S(L)	T(LSF)	1163099.	18	64616.6	7.08	0.0
LF	SF(L)	591632.	4	147907.9	28.04	0.0000
SF(L)	T(LSF)	379828.	72	5275.4	0.58	0.9976
T(LSF)		4565222.	500	9130.4		

Table 2: ANOVA Summary for Inter-stress Interval 2

inter-stress intervals themselves are the unit, in which case it would only be due to the duration, not the internal composition, of the units.

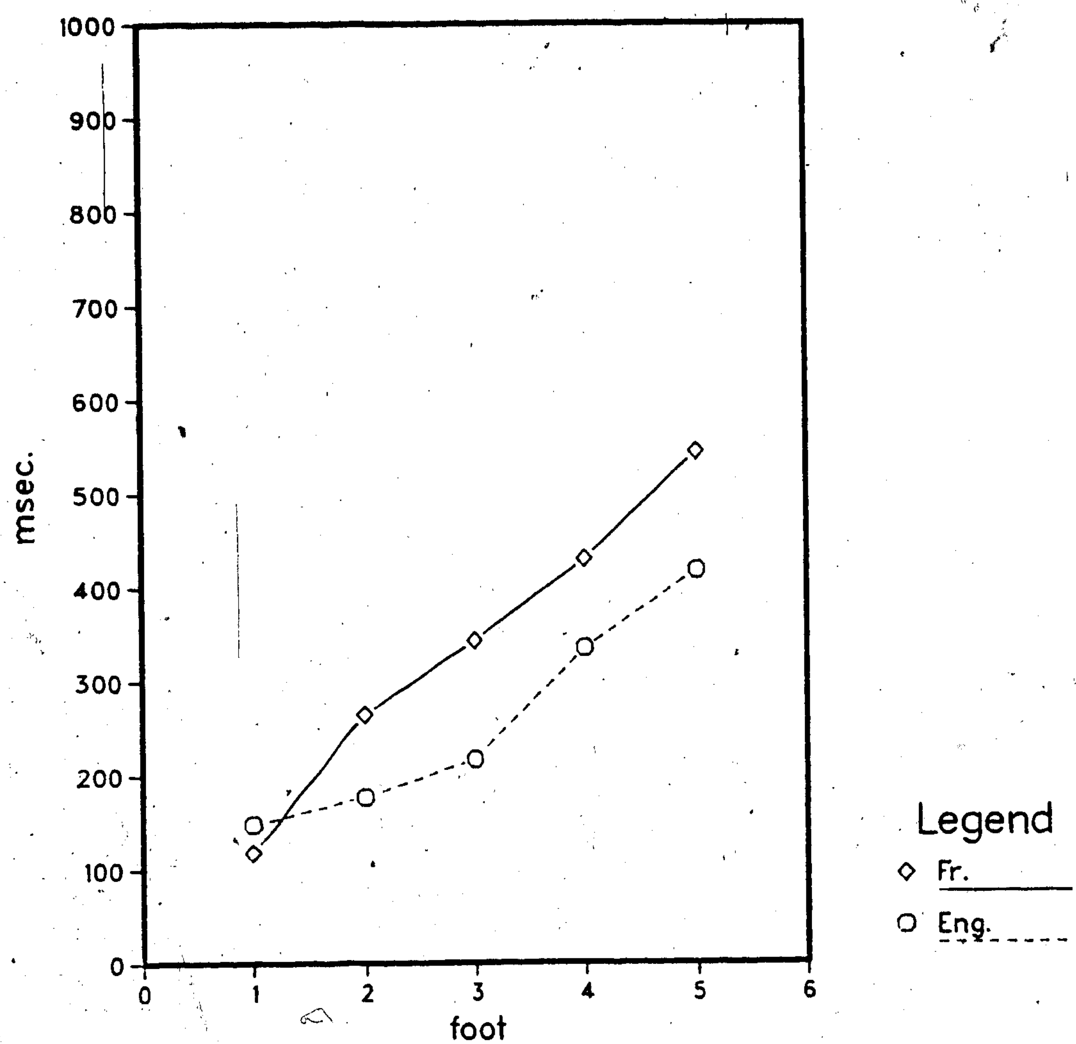
The analysis of ISI1 and ISI2 for feet 1 to 4 indicates that English and French are, indeed, more similar if the longest inter-stress interval measured is disregarded ($F = 5.63$, d.f. = 3, $p < 0.0020$; $F = 18.22$, d.f. = 3, $p < 0.0000$). This upholds the contention that the two languages are more reliably differentiated by their longer feet. As a double-check, I ran an analysis of the ISI1 duration for feet 1 to 3, which gave $F = 5.25$, d.f. = 2, $p < 0.0100$. While such a result could also be due to the languages being similar at one particular foot size, with increasing dissimilarity as foot size changes (i.e. stress versus syllable isochrony), the graph of the inter-stress interval (Figure 1) shows clearly that this is not the case. Both languages follow a similar curve, with the difference in duration between them increasing gradually as the foot size grows. Thus, for ISI1, the French duration minus the English duration is for foot 1: 34.3 msec., foot 2:

86.5 msec., foot 3: 88.3 msec., foot 4: 126.7 msec. and foot 5: 216.3 msec. We see that, as foot size increases, the durational difference does too, by 120.8, 1.8, 38.4 and 89.6 msec. respectively. Although this result could show the "tendency" to isochronism often put forward, it shows even more strongly the lack of isochronism. The difference in duration between the two languages is not in direct proportion to the foot size, as would be predicted by isochrony. It is also clear that the predictions of stress and syllable isochrony, shown in Figure 1 as Stress and Syllable, do not match the observed data from the subjects.

B. Vowel (V)

Total vowel duration is reliably differentiated ($F = 33.68$, d.f. = 4, $p < 0.0000$) using both all five feet, and only foot 1 to foot 4 ($F = 49.32$, d.f. = 3, $p < 0.0000$). In fact, deleting foot 5 had little effect; even the numbers stayed close. Once again, Figure 2 helps to show the reason. In foot 1, the difference is small: 30.8 msec. Also, foot 1 is the only condition in which English had a longer vowel duration. For the other feet, the difference stays fairly constant: 88.5 msec., 126.0 msec., 95.5 msec. and 125.8 msec. Under the assumption that vowels in the two languages are of an equivalent "inherent" duration, which is not unlikely as the foot 1 means show similar vowel durations, this would argue against the premise of vowel compression being used in English but not in French. If this

Figure 2 — Total Vowel Duration



SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	53787210.0	1	53787210.	1366.11	0.0000
L	S(L)	988285.	1	988285.3	25.10	0.0001
F	SF(L)	8886861.	4	2221715.2	601.11	0.0000
S(L)	T(LSF)	708703.	18	39372.4	7.55	0.0
LF	SF(L)	497952.	4	124488.0	33.68	0.0000
SF(L)	T(LSF)	266113.	72	3696.0	0.71	0.9644
T(LSF)		2607993.	500	5216.0		

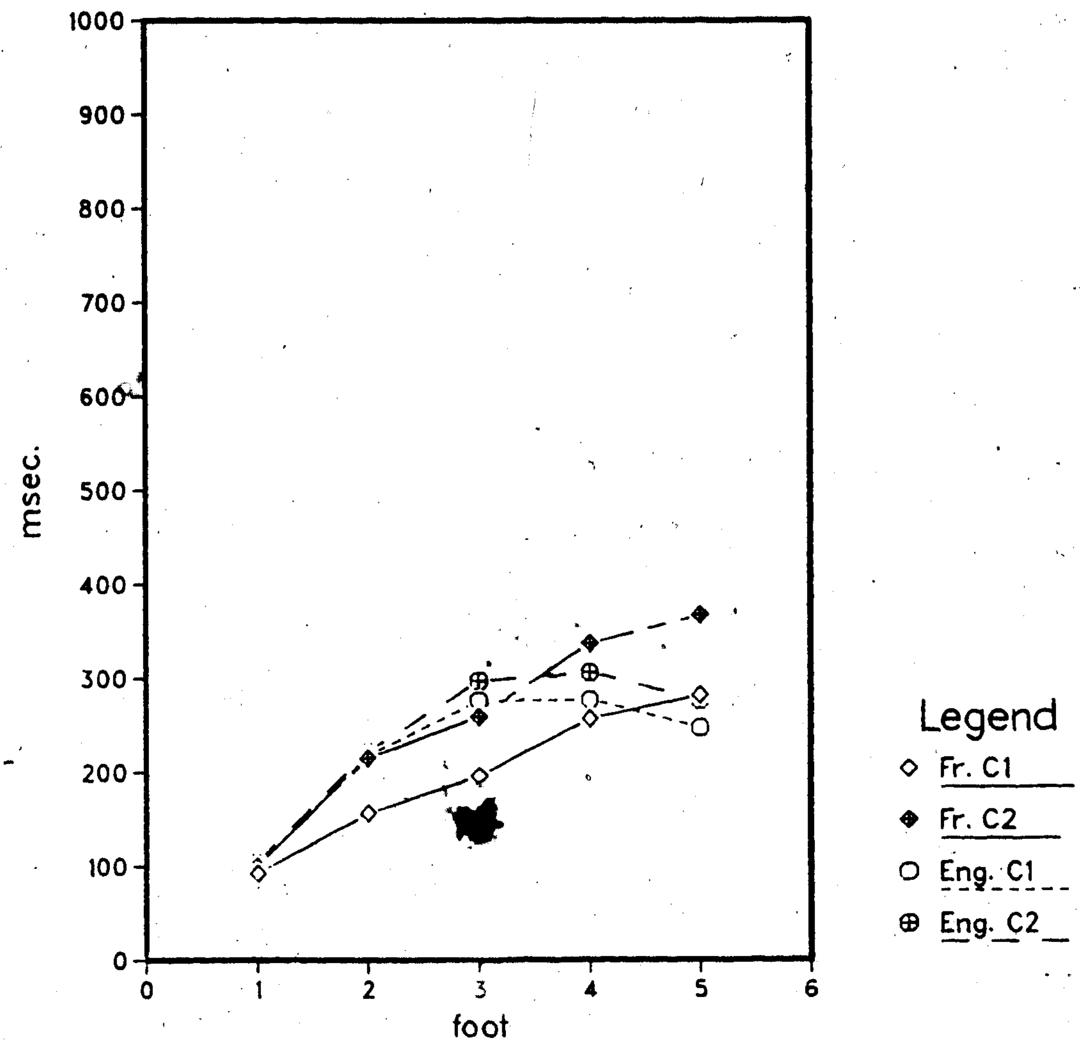
Table 3: ANOVA Summary for Vowel 1

were the case, the languages should diverge to a greater extent as more vowels occur in the inter-stress interval. However, there does seem to be greater variability in the duration of the English vowels. This is evidenced by the relatively slow linear growth of vowel duration for feet 1, 2 and 3, followed by a much greater increase, but still in a linear fashion, for feet 4 and 5. This indicates that some form of compression must be occurring, as the differences in V for the feet are 29.1, 39.9, 117.8 and 83.4 msec. In French, these values are 147.5, 77.4, 87.4 and 113.5 msec.

C. Consonant 1 and 2 (C1 and C2)

Total consonant duration indicates that the two languages are also dissimilar. It is only when pause time is included as part of the consonant duration that the speaker groups cannot be reliably separated. Consonant duration for all five feet showed $F = 23.60$, d.f. = 4, $p < 0.0000$ and consonant duration for feet 1 to 4 gave $F = 16.19$, d.f. = 3, $p < 0.0000$. However, inter-vowel duration (consonant duration + pause) gives $F = 2.97$, d.f. = 4, $p < 0.0251$ for

Figure 3 — Consonant Duration



SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	26487727.	1	26487727.3	2747.59	0.0000
L	S(L)	109134.	1	109134.1	11.32	0.0035
F	SF(L)	2446868.	4	611716.9	228.20	0.0000
S(L)	T(LSF)	173526.	18	9640.4	1.06	0.3895
LF	SF(L)	253026.	4	63256.4	23.60	0.0000
SF(L)	T(LSF)	193001.	72	2680.6	0.29	1.0000
T(LSF)		4543846.	500	9087.7		

Table 4: ANOVA Summary for Consonant 1

all feet, F = 1.03, d.f.= 3, p < 0.3871 for feet 1 to 4. While this is interesting, I do not believe that pause time can be added to consonant duration to produce a variable of any meaning. It can only be defined as the non-vocalic portion of the utterance, not as a coherent group. For this reason, consonant duration is a more telling variable. Even here, however, there is a problem, because the measured stimuli do not compose a random sample of the consonants of the languages studied. This is due to the choice of inter-stress intervals containing an abundance of stops, affricates and fricatives and as few glides and liquids as possible. Although this adds to the ease of measurement, it compounds the problem of applying the analysis of the consonants sampled to a larger sample of either language. However, comparison of the proportion of fricatives, stops, nasals, liquids, glides and affricates in the sample to those occurring in text counts of the language indicated that it is reasonable to term the sample representative.

Figure 3 shows why the languages can be differentiated. The English subjects decrease the duration from foot 3 to

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	36988754.	1	36988754.	381.03	0.0000
L	S(L)	32975.	1	32975.	0.34	0.5672
F	SF(L)	4073083.	4	1018271.	41.18	0.0000
S(L)	T(LSF)	1747381.	18	97077.	3.81	0.0000
LF	SF(L)	293462.	4	73366.	2.97	0.0251
SF(L)	T(LSF)	1780476.	72	24729.	0.97	0.5492
T(LSF)		12742403.	500	25485.		

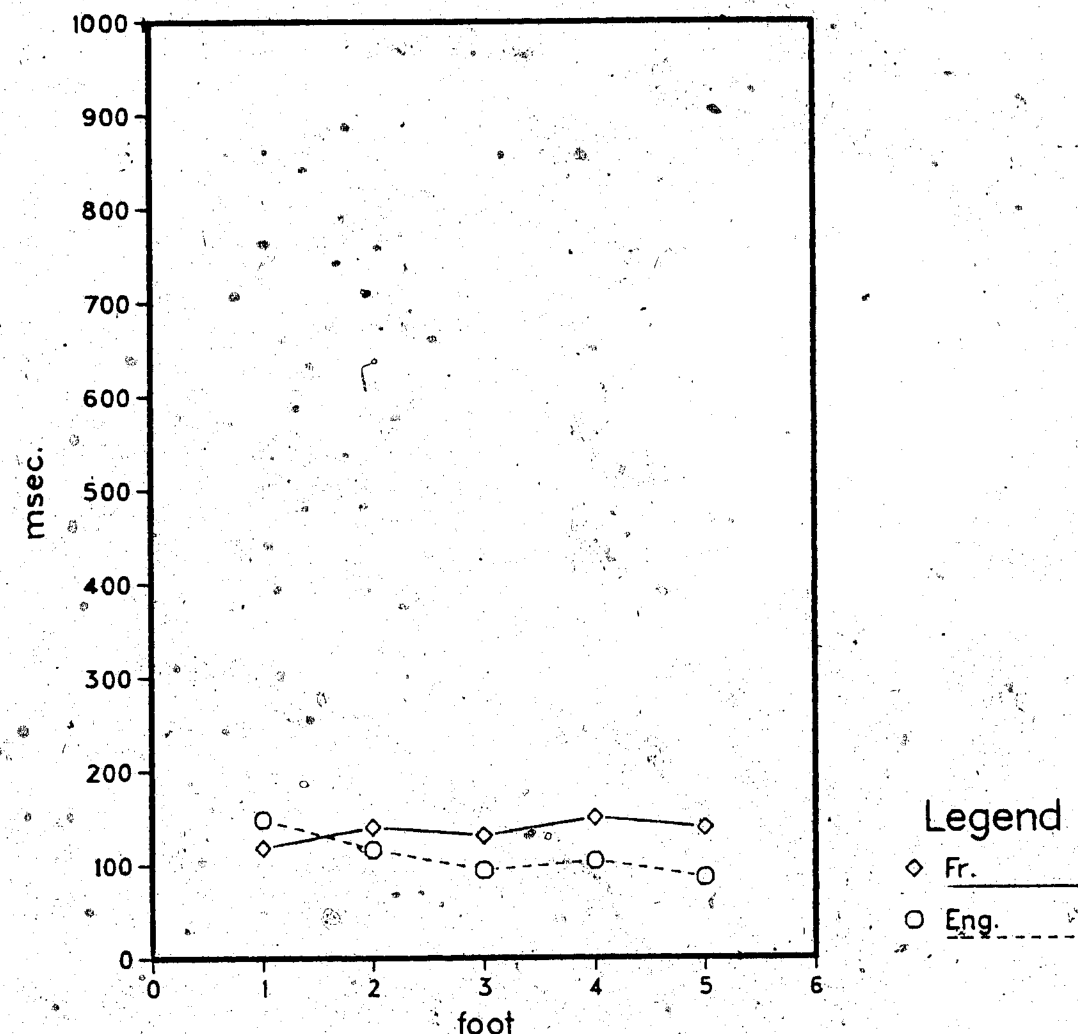
Table 5: ANOVA Summary for Consonant 2

foot 5 while the French subjects do not. As well, the French consonant duration (C1) is less than that of English for foot 4. This does support the isochrony hypotheses, although the effect is less than would be required to fulfill them. Also, the values for the English subjects counteract the values obtained for the vowel duration, giving the ISI graphs a more linear appearance than either of its two main components.

D. Stressed Vowel (StV)

Analysis of the average stressed vowel duration for each foot helps us to understand why the languages are different (feet 1 to 5: $F = 41.05$, d.f. = 4, $p < 0.0000$; feet 1 to 4: $F = 39.21$, d.f. = 3, $p < 0.0000$). For the English subjects, the stressed vowel is longest in foot 1 with a gradual shortening as the foot size increases. There is a slight increase between feet 3 and 4, but this is likely due to the vowels sampled. This lends credence to the idea of vowel compression. However, it must be compensated for as French shows similar compression for total vowel

Figure 4 — Stressed Vowel Duration



SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	9016004.	1	9016004.17	948.07	0.0000
L	S(L)	101816.	1	101816.43	10.71	0.0042
F	SF(L)	44109.	4	11027.28	13.74	0.0000
S(L)	T(LSF)	171176.	18	9509.80	5.43	0.0
LF	SF(L)	131796.	4	32949.01	41.05	0.0000
SF(L)	T(LSF)	57793.	72	802.68	0.46	1.0000
T(LSF)		875467.	500	1750.93		

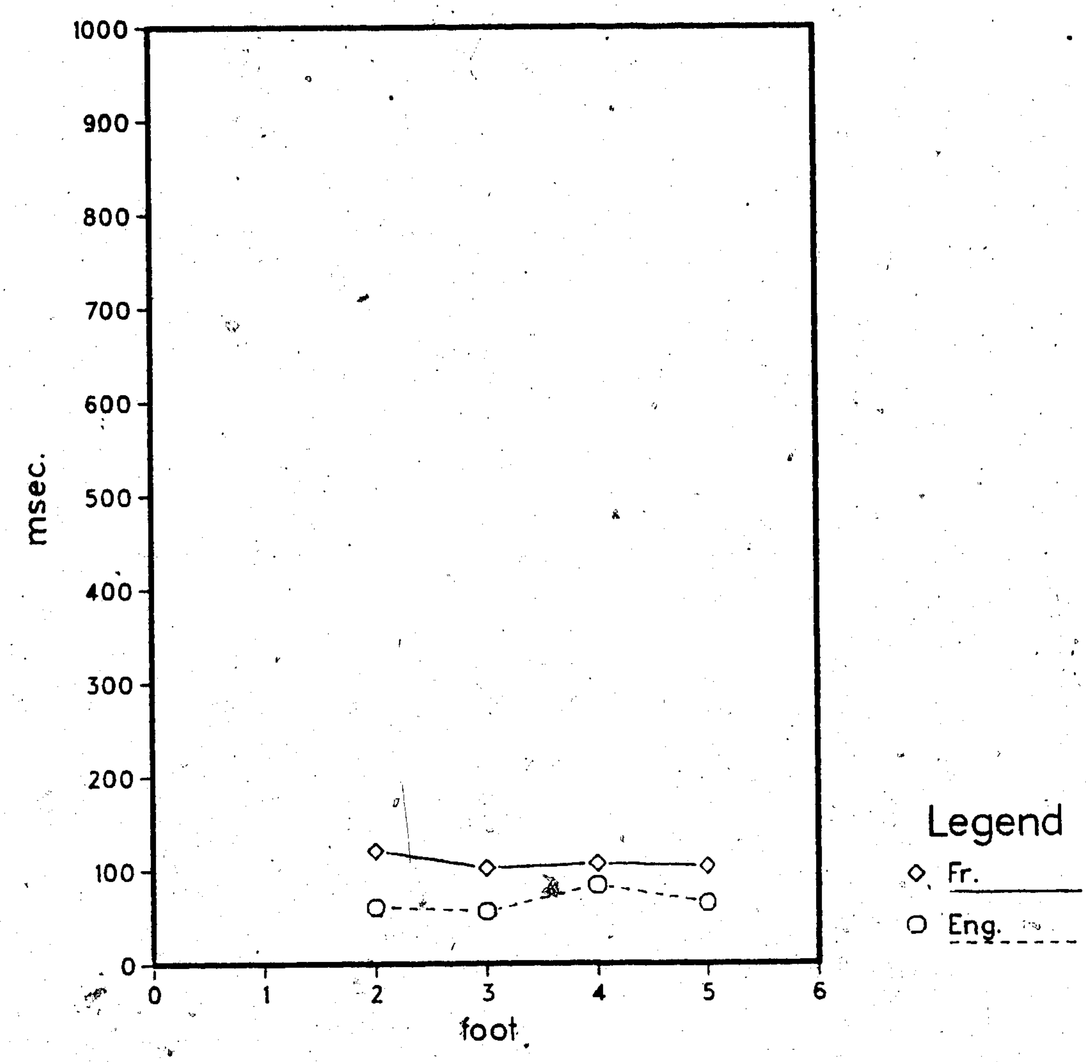
Table 6: ANOVA Summary for Stressed Vowel

duration. The French subjects showed foot 1 to have the shortest stressed vowel duration, with an increase of about 25 msec. to a basically stable duration for the other feet. Obviously, this is contrary to compression. Another point is that the feet themselves can be differentiated by the stressed vowel duration ($F = 13.74$, d.f. = 4, $p < 0.0000$).

E. Unstressed Vowel (1UstV)

Although the term "unstressed" is not necessarily applicable to French in the same sense as English, several researchers (Crompton, 1980; Delattre, 1966; Wenk & Wioland, 1982) have admitted the term stressed or accented in their analyses of French timing patterns. This leads to the admission of unstressed syllables, as the stressed ones must be in opposition to another type. The tokens chosen for analysis were selected on the basis of grammatical stress. Despite this, fourteen of the twenty-four samples had a monosyllabic grammatical morpheme in the first unstressed vowel position (e.g. de, la).

Figure 5 – First Unstressed Vowel Duration



SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	3656473.	1	3656473.41	1435.44	0.0000
L	S(L)	210925.	1	210924.67	82.80	0.0000
F	SF(L)	18701.	3	6233.64	9.46	0.0000
S(L)	T(LSF)	45851.	18	2547.29	2.26	0.0025
LF	SF(L)	21674.	3	7224.58	10.97	0.0000
SF(L)	T(LSF)	35568.	54	658.67	0.58	0.9918
T(LSF)		451574.	400	1128.93		

Table 7: ANOVA Summary for Unstressed Vowel

The data analysis clearly indicates that English and French are differentiated by the duration of the first unstressed vowel after the stressed vowel ($F = 10.97$, d.f = 3, $p < 0.0000$). Even looking at only feet 2 to 4 did not alter this response ($F = 14.90$, d.f. = 2, $p < 0.0000$). Looking at the means for the two languages helps to show why: English 66 msec. versus French 108 msec. Figure 5 shows more clearly how distinct the treatment of the first unstressed vowel is; while the plots for all the other measurements cross, these are separate. Another interesting point is that, while French shows some small evidence of compression, English does not. In fact, the English values show evidence that the duration of the first unstressed vowel is constant across the feet sampled. Because there is no convincing hypothesis to account for foot 4 having a longer unstressed vowel duration, I assume this result was due to sampling. French presents a problem; the longer unstressed vowel of foot 2 argues against syllable-timing. However, this could again be due to sampling, in which case the duration would be constant across all feet, which could be interpreted as supporting syllable-timing. With the data at hand, it is not possible to choose between these alternatives, although the small variation displayed in the other feet might argue for sampling error. No matter which hypothesis is true, the data show that English and French do not treat the unstressed vowel similarly.

The foot factor is also significant ($F = 9.46$, d.f. = 3, $p < 0.0000$), indicating that the durations of the first unstressed vowel in different feet are not similar. This can again be traced to foot 4 in English and foot 2 in French.

F. Ratios

As a further check, the ratios of components of the inter-stress interval to the inter-stress interval itself were calculated. The results are shown in Figure 6 for ISI1 and Figure 7 for ISI2. From these graphs, we can see that the difference between English and French is not due only to rate. Although French speakers showed a longer duration for all rhythmic feet except foot 1, any changes attributable solely to rate would be washed out by a ratio comparison. However, it is only in the stressed vowel/inter-stress interval ratio that the two languages are similar. Thus, we can conclude that we cannot attribute the differences observed between English and French speakers to a faster or slower speaking rate for the speakers of the language.

Figure 6 - ISI1 Ratios

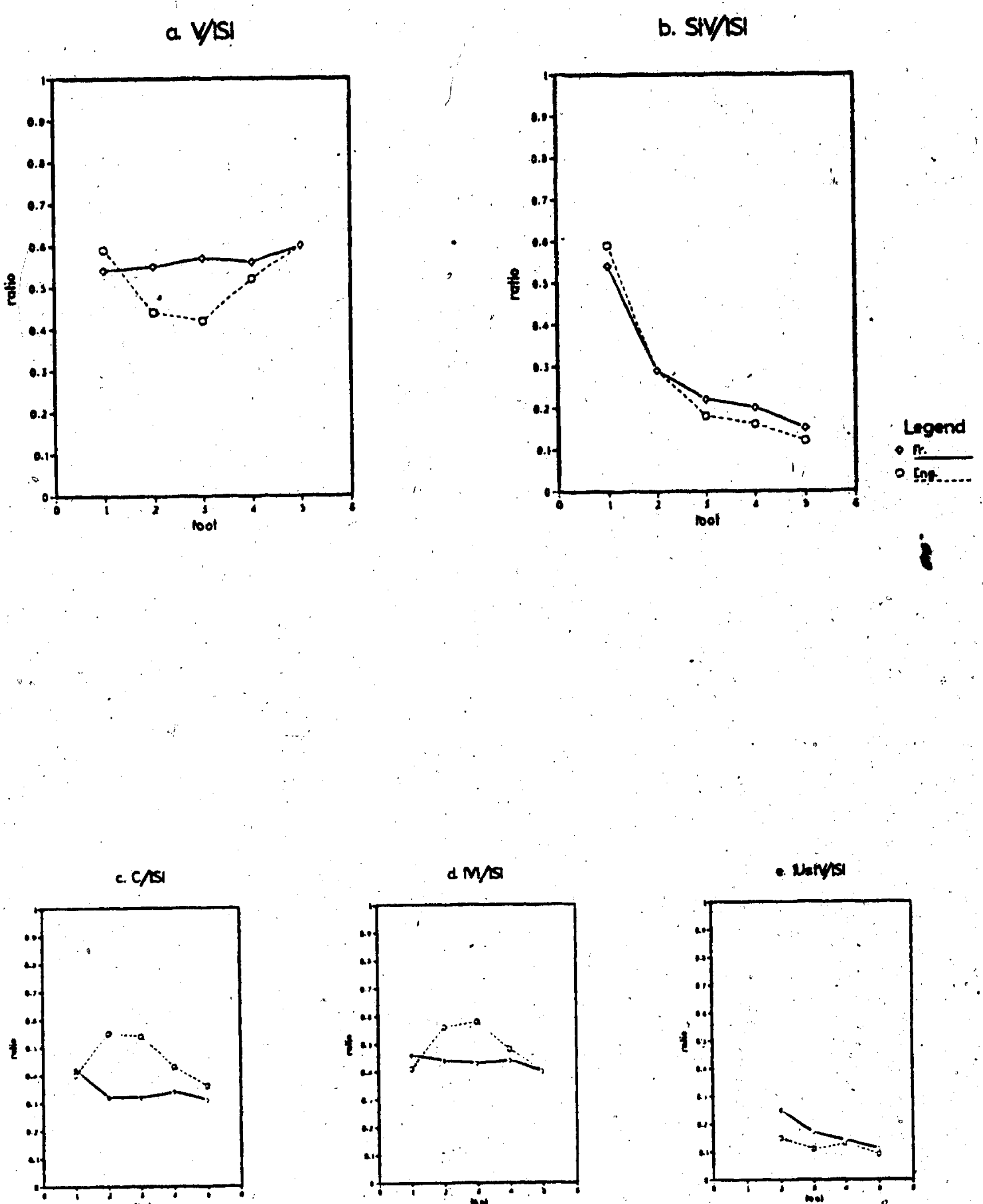
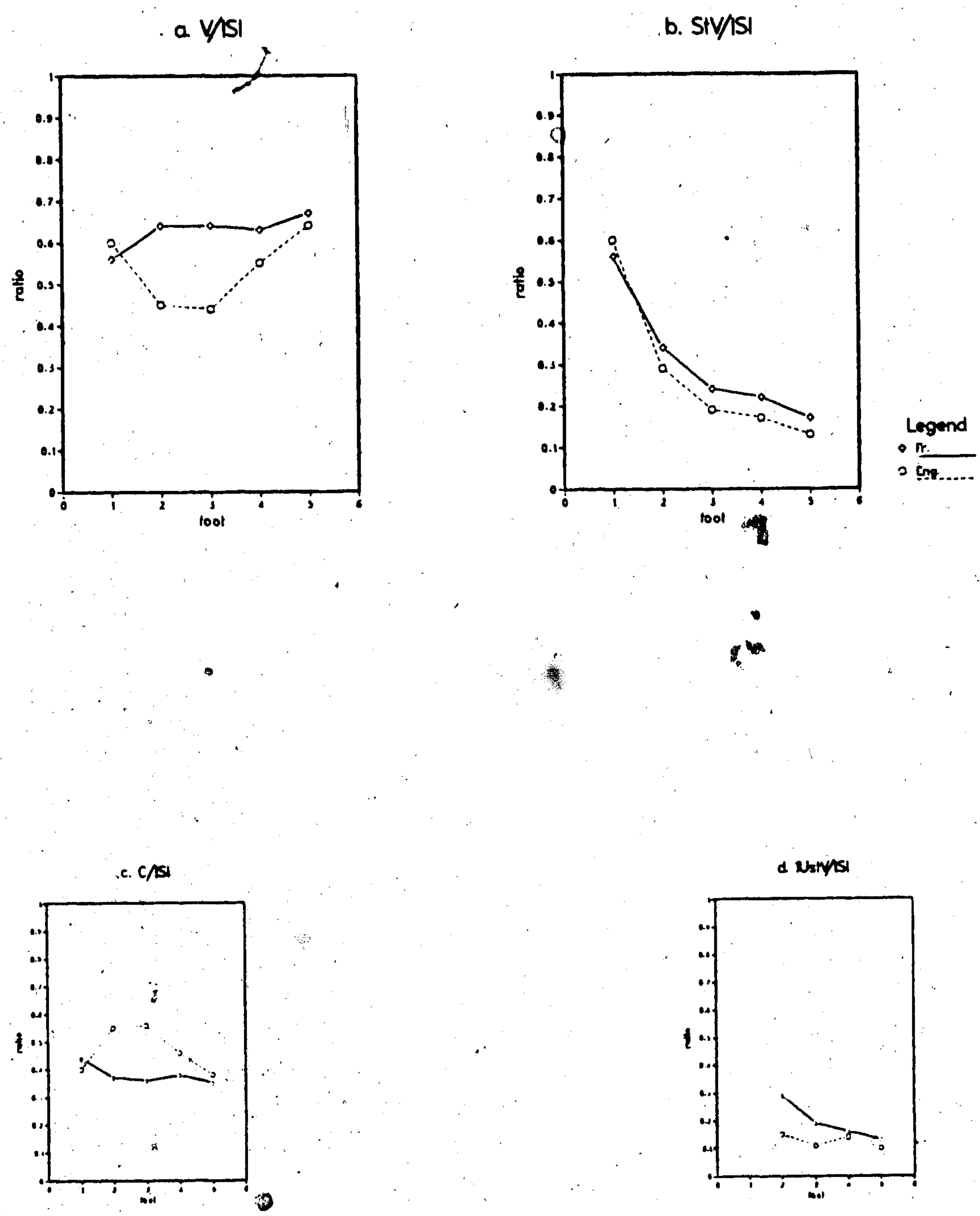


Figure 7 - ISI2 Ratios



V. DISCUSSION

A. Isochrony

As shown in the data analysis and figures of chapter 4, the subjects in this study do not show any evidence of isochrony. The average syllable length decreases and the average inter-stress interval increases as the size of the rhythmic feet grows. Taken on its own, this is no challenge to the hypotheses, of course. The problem arises because no study has yet been able to produce clear evidence of isochronic timing influencing language output. With these replications, the chance of finding these factors affecting speech is minimal. Looking at Figure 1, it is clear that the hypothesized tendencies in each language impose a small differentiation between them, especially in the shorter rhythmic feet (1, 2 & 3) which compose the large majority of spoken language, e.g. Uldall (1971, 1978): 88% of the feet were one to three syllables at normal rate and 76% at fast rate; Krishnan (1983): feet 1 to 3 contain 87% of the rhythmic feet in two texts analyzed. It, therefore, seems fair to say that, in running speech, the isochrony will have to be evident in these smaller units. The analyses show, however, that it is only in the larger units that the two languages are reliably distinguished.

There is a problem associated with this approach. Merely because a statistical analysis indicates that two groups can be regarded as significantly different does not mean that those differences are detectable by people during speech. We must keep in mind that our perceptual systems also impose limitations on what can be used to differentiate speech. So, for example, even if we apply Lehiste's (1977) criterion that the durational difference needs to be 30 to 100 msec. before it can be accurately perceived, it is plain that listeners could accurately choose which inter-stress interval, English or French, is longest in an AB comparison test. But does this allow them to also perceive one as syllable-timed and the other as stress-timed? Again, such comparison evaluation would allow a speaker of English to invariably distinguish the different rhythmic feet on the basis of their duration alone, with the possible exception of the increase reported from foot 4 to foot 5. This is, however, only looking at average values collapsed across tokens. Obviously, any specific example will have some variation from these figures and the upper limit of the range of one foot, in fact, shares the durational values associated with the lower limit of the next larger foot. This means that a foot 2 can have the same, or even longer, duration as a neighbouring foot 3. On average, though, the reverse will be true. This same argument applies to French, as syllable length ranges from 182 to 242 msec. for foot 1. This means the question is how are these discernible differences in syllable and inter-stress interval length glossed over by speakers/hearers?

Lehiste's (1977) answer that stress isochronicity relies on an interdependence of production and perception tendencies is unconvincing because it does not explain why French speakers do not show this tendency. For this production/perception explanation to hold true, there would have to be some method of setting the value at the mora, syllable or stress level. Otherwise, we must postulate a mechanism which is either overridden or undeveloped in a large number of languages, i.e. those not stress-timed. Of course, the biggest drawback is the lack of a definition for "tendency". Hill, Witten & Jassem (1978) found that the attempt to maintain a constant inter-stress interval in English accounted for only 9% of the variation in segment duration. Is this 9% influence on segment duration sufficient to establish English as stress-timed? This leads one to ask what the corresponding figure for French speakers is. On the assumption that the other factors, i.e. phoneme type, syllable type, rhythmic unit, that Hill et al. (1978) found to be important contributors to speech sound duration contribute the same overall effect in French as in English, the effect of trying to maintain a constant syllable duration is unlikely to reach above 10%. Thus, if we assumed the two languages to differ only in terms of their tendencies in production, this would lead to a gradual widening of the gap between them as the number of syllables present in the foot increased. The evidence from this experiment is inconclusive in this regard, as the absolute durational difference between English and French does increase, but not at a constant rate as suggested by this hypothesis. Even converting the difference to a percentage of average inter-stress interval does not lend itself to this interpretation; the results are, for foot 1 through 5: 14.6, 19.6, 15.8, 18.0, 27.0%. Here again, it is in the larger rhythmic feet that the analysis runs into problems. Interestingly, by using inter-stress interval without pause or repetition, the figure for foot 5 reduces to 20.9%, much more in accord with the others. However, the values for the smaller feet then become: 16.8, 5.1, 8.9, 11.2%. Neither the absolute nor the ratio values support this possibility.

On the other hand, the results reported here also argue against Nakatani et al.'s (1981) claim that English displays an increase in inter-stress interval directly related to the number of syllables. Figure 1 shows that the increase in inter-stress interval is not consistent, but shows evidence of a gradual shortening of average syllable duration (English: 252, 199, 171, 160, 139 msec.; French: 218, 242, 201, 192, 182 msec.) This could, however, be caused by constant durations for longer stressed syllables and shorter unstressed syllables, which would also lead to the same effect. Another minor consideration is that the stressed vowels were not measured with their consonants. Therefore, I calculated the average unstressed syllable duration as well. This duration has the disadvantage of also including the consonant before the final stressed vowel of the inter-stress interval, but, again due to sampling, the effect is to lengthen all the unstressed syllables in the foot. There is also a slight predisposition toward exaggerating the effect of the compression as the consonant duration is divided between more syllables. However, the amount of the reduction in syllable duration shows that this cannot be merely due to the extra consonant. For the English subjects, the values, starting at foot 1, are: 282.1, 210.0, 178.9 and 152.0 msec. Interestingly, the absolute amount of reduction in French is even greater: 344.8, 235.4, 205.8 and 192.7 msec. These results contradict the hypothesis of linear increase in inter-stress interval due to foot size.

B. "Universal" Timing

The analyses of the data indicate that the English and French subjects are significantly different (at the 0.05 level or beyond) on six of the seven measures [illegible] namely inter-stress interval 1, inter-stress interval 2, vowel, consonant, stressed vowel and first unstressed vowel duration. Only in inter-vowel duration are the two groups similar. Inspection of the graphs of the L x F interaction (Figures 1 to 5) indicated that the languages were differentiated, in most cases, by the longer inter-stress intervals, as the lines diverged in an accelerating fashion. Therefore, I also ran analyses on the measurements for feet 1 to 4. This reduced the number of significant results to four: vowel, consonant, stressed vowel and first unstressed

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	112735406.	1	112735406.	712.35	0.0000
L	S(L)	535068.	1	535068.	3.38	0.0825
F	SF(L)	14132172.	3	4710724.	180.98	0.0000
S(L)	T(LSF)	2848642.	18	158258.	5.49	0.0
LF	SF(L)	439376.	3	146459.	5.63	0.0020
SF(L)	T(LSF)	1405551.	54	26029.	0.90	0.6698
T(LSF)		11532721.	400	28832.		

Table 8: ANOVA Summary for ISI1 (Feet 1 to 4)

vowel duration. I believe it to be meaningful that the inter-stress interval overall measurements dropped out, while the individual components remained different. Under the stress versus syllable isochrony hypothesis, the inter-stress intervals themselves would only become similar at the level of foot 1 or 2, depending on how the isochronic inter-stress interval is defined. The opposing view, which uses an underlying universal timing hypothesis with an overlay of language structure would predict the observed result, however. The two languages alter each individual component differently, and yet obtain similar results. Assuming the effects of language structure to be cumulative as more unstressed syllables are counted, the difference between the languages would gradually decrease as fewer syllables occur in the inter-stress interval. Therefore, consonants and vowels are significantly different while the inter-stress intervals are not.

This supports Dauer's (1983) hypothesis that languages share a common timing character, with the differences between them arising from language structure and the

SOURCE	ERROR TERM	SUM OF SQUARES	D.F.	MEAN SQUARE	F	PROB.
MEAN	S(L)	96590758.	1	96590757.7	2499.28	0.0000
L	S(L)	75551.	1	75551.0	1.95	0.1791
F	SF(L)	11136447.	3	3712149.2	1002.87	0.0000
S(L)	T(LSF)	695654.	18	38647.4	4.35	0.0
LF	SF(L)	202348.	3	67449.4	18.22	0.0000
SF(L)	T(LSF)	199882.	54	3701.5	0.42	0.9999
T(LSF)		3553186.	400	8883.0		

Table 9: ANOVA Summary for ISI2 (Feet 1 to 4)

influence of stress on the linguistic system. There is, however, a problem in that he suggested that languages operate with an inter-stress interval of about half a second, and an unstressed syllable having the effect of adding 110 msec. to a foot. The data here indicate that the English subjects almost precisely match these measurements, an average inter-stress interval of 499.7 msec. and an average increase per foot of 110.4 msec. French subjects showed an average inter-stress interval of 596.3 msec. and an average increase per foot of 173.0 msec., which are well above Dauer's values. One explanation could be that the French subjects, for whatever reason, read more hesitantly and that similar results could only be obtained when the pause durations were eliminated. Then, the durations are 530.1 msec. and 149.1 msec. Although these values are still high, they do not seem unlikely, given the small number of subjects sampled from the total population. For English, these ISI2 values are also within the likely limits, 479.6 msec. and 101.4 msec. Therefore, it is only in fluent speech that the subjects show the timing characteristics which Dauer suggests. Goldman-Eisler (1968) claims that over 60% of spoken language consists of groupings of less than six words. Also, Klatt (1976) says that, even in fluent reading, pauses make up 20% of the time required. This means that pauses, which occur most frequently at major syntactic gaps or before words with a high information content, are a part of nearly any language utterance and will need to be taken into account. If, as seems likely, Dauer's figures are arrived at on the basis of speech without pauses, they will not reflect the correct durations associated with these intervals.

Another inconsistent finding was that the English foot 1 had an only slightly longer duration than the French foot 1. Making the assumption that Spanish and French have a similar syllable duration, on the basis both of being classified as syllable-timed languages and Delattre's (1966) measurements, the English foot 1 should be equal in duration to the French foot 2, according to Dauer's findings. In this study, the corresponding figures are 252 msec. and 484.9 msec. There is little question that this difference of 232.9 msec. would be apparent to hearers (i.e. it is almost double the length).

C. Total Vowel Duration

Total vowel duration shows a very obvious difference between English and French (see Figure 2). For foot 1 and foot 2, this measure lives up to the claims of stress and syllable isochrony. The English duration increases by only 29 msec. (147.8 to 176.9 msec.) while that of French more than doubles (117.9 to 265.4 msec.). However, after this brief support, both languages show identical increases as the foot size grows, which contradicts both isochronicity hypotheses. It seems that the vowel compression which occurs in English can only make a significant contribution to a constant inter-stress interval when the feet are small. For example, the vowel duration in English increases by 29, 40, 118 and 83 msec., while in French it is 147, 77, 87 and 113 msec. These figures could help to explain why English is felt to be stress isochronic, and French to be syllable isochronic. Roughly 80% of inter-stress intervals in English are from foot 1 to 3. Since it is in these inter-stress intervals that the vowel duration is most strongly resistant to any increase, it is possible that the psychological response of isochronicity results from an analysis of this variable. Especially as we have already seen that inter-stress interval duration shows no evidence of stress-timing and little of syllable-timing. Therefore, to find that vowel duration only varies by 69 msec. between foot 1 and 3 in English while, for French, the figure is 224 msec. raises the possibility that judgements of isochronicity are actually cued by overall vowel duration rather than inter-stress interval. This is also supported by the fact that none of the other measurements show a strong tendency towards both forms of isochronicity postulated for the languages. Even in this factor, though, this does not hold true beyond foot 3, at which point English loses any semblance of stress isochronicity and French begins to fall away from syllable isochronicity. Although an explanation of this is possible, i.e. considering that the more common foot sizes are more strictly regulated by isochronic timing because of their greater frequency and, therefore, contribution to rhythm, it seems to introduce complexity more than answer the question of why this difference occurs.

The vowel duration data also support Uldall's (1971, 1978) hypothesis that the longer feet are somehow counted as two feet in the judgement of isochrony. This was her way of accounting for the fact that the four syllable feet did not fall into line with the duration measurements of the shorter feet. If we assume that "longer feet" means foot 4 and 5, we find the average duration for foot 1 to 3 to be 180.5 msec. and foot 4 and 5 to be 376.3 msec., i.e. 188.2 msec. when counted as two feet. Of course, this coincidence is displaced when we calculate the same data for French: foot 1 to 3 gives 242.1 msec., foot 4 and 5 is 487 msec., i.e. 243.5 msec. as two feet. Not only does it seem that such a calculation would impede the transmission of information, which is usually the aim of language, but it would imply that French is as stress isochronic as English. Actually, this calculation should work better with a syllable-timed language, as the average number of syllables is two for the shorter group and two and quarter for the larger. Claiming that English speakers count foot 4 and 5 as two inter-stress intervals is, therefore, to argue that it is not stress isochronic.

D. Stressed Vowel

On this measure, English and French show opposite tendencies. The English speakers show some evidence of compression as foot size increases, such that the decline from foot 1 to foot 5 is 63 msec., from 147.8 msec. to 85.7 msec. This lends some support to the contention that feet are one of the units used in speech planning. However, this is not the only possibility. If the larger feet contained stressed vowels followed by a voiceless consonant and/or not in the final syllable of the word (Klatt, 1973) while the shorter feet did not, we would expect the vowel duration to shorten by as much as 45% of its duration. For English, this value is actually 42%. Since the correlation of foot size and segment composition is unattested, it seems that the rhythmic feet enter into speech planning.

On this basis, it is hard to understand why the French subjects show an increase of 21 msec. in stressed vowel duration as foot size increases from foot 1 to foot 5. Note, however, that the total range covers 32 msec., as foot 4 has the longest stressed vowel duration. Even so, this is only one half of the range in English. Due to this small variation in duration, it is likely that the values for the French subjects display a constant duration for this factor, with the deviation attributable to random sources, such as sampling error and local variation in speech rate. In this case, the constant duration would argue in favour of the syllable-timed hypothesis. The larger range of the English subjects gives support to the stress-timing hypothesis. At the same time, they show that such effects are only tendencies, at best, as the amount of time involved shows too much variation to be ignored in French and not enough to keep the inter-stress interval constant in English.

Dauer's (1983) suggestion that English is more stress-based than French could run counter to these findings. If English considers stress to be important, why does the amount of time taken to utter the stressed syllable decrease as foot size increases? Such a result is descriptive of a language which is not stress-based, if stressed syllables are told by vowel duration. Since English depends on an amalgamation of duration, amplitude and pitch to delineate its stressed vowels (Delattre, 1966), we can combine this with listeners' proven ability to use relative durations of adjacent segments to understand how English can allow stressed syllables to shorten.

E. Consonants 1 and 2

One question which remains is why the consonant duration, both C1 and C2, shows no sign of an increase directly correlated with foot size. Earlier studies have indicated that the compression observed in English results from adjustments to the vowel durations with less influence on the consonants (Dauer, 1983; Klatt, 1976). This implies that consonant duration for English should be proportional to foot size, which is definitely not the case. If we divide consonant duration by foot size, it is clear that the average decreases: 100, 109, 92, 69 and 49 msec. Such a decrease could not be due to including an extra consonant in each duration (i.e. the consonant before the second stressed vowel), as this would lead to a smaller geometrical decrease. However, it is also true that this extra consonant will exaggerate the effect of the decrease. Average consonant duration, calculated by dividing consonant duration by the number of inter-vocalic consonants or consonant clusters, is not constant as foot size increases: 50.2, 72.8, 69.0, 55.3 and 41.1 msec., in comparison to French: 45.9, 51.9, 49.0, 51.5 and 47.1 msec., a range of 6 msec. A way to discount the extra consonant or consonant cluster before the foot-final stressed vowel is to look at the increase in consonant duration between foot sizes. Here, the English values show a consistent decline as foot size increases: 118.1, 57.3, 0.8, and -30.0 msec., against a more stable rise in French: 63.9, 40.1, 61.6, and 25.0 msec. These data support both hypotheses of isochronicity. If the average increase in consonant duration were to diminish with foot size in French, the vocalic portion of the foot would have to take up a greater percentage in order to maintain equal syllable durations. Alternatively, English would require the vowel duration to shorten accordingly in order to add a constant consonant duration while even tending to hold inter-stress interval fixed. Even so, it is questionable whether the consonantal portion could cue the listener's rhythmic judgement. Most researchers have agreed that either stressed vowels or all vowels are the main cue used (Allen, 1975; Nooteboom, 1972), which would make it possible for a listener to use both vowel onset and consonant duration to judge the rhythm of an utterance. The only problem with this is that French shows, for the most common foot sizes, a more stress isochronic appearance than English.

F. Unstressed Vowel

The data on the first unstressed vowel show strong evidence that English and French are very dissimilar in their treatment of this factor, which is reflected in its obtaining the highest F ratio in the ANOVA. However, of greater interest from the viewpoint of isochrony is the lack of compression exhibited by the English subjects. Apart from foot 4, 1UstV retains a constant duration across all four feet. This once again indicates the problem of trying to show English as stress isochronous. For even a tendency towards this timing to be evident, the duration of this vowel should show a decrease as foot size increases. Instead, the measurements for the English subjects show that this interval does not shorten. The data indicate that

English is more syllable isochronic in this respect than French, especially as the foot 4 measurements could be affected by measurement error due to segmental composition. This was the only foot with three occurrences of /ɚ/, while the other feet had a higher percentage of stops or fricatives after the vowel. As well, the three /ɚ/ vowels have an average duration of 96.0 msec., compared to 65.1 msec. for the other three vowels for the foot. Because the average duration of these three is the same as feet 2, 3 and 4, it is likely that the unstressed duration of foot 4 is artificially inflated by the inclusion of a portion of the acoustic wave of the /r/ following the vowel.

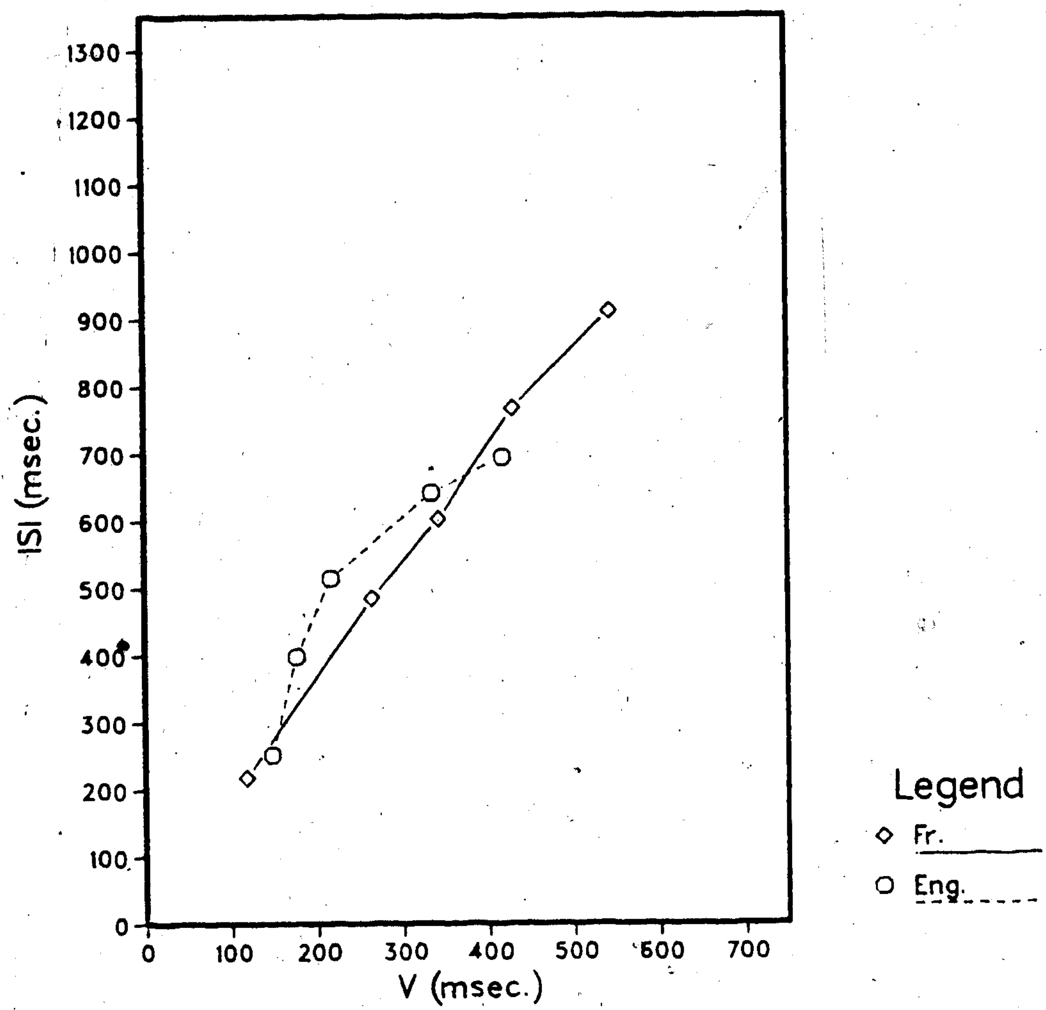
This has some bearing on the question of whether the vowel /ɚ/ is one sound, as indicated by the use of one symbol, or is a sequence of two segments. If this vowel were one segment, it should show a duration equivalent to the other unstressed vowels occurring in a similar environment. Since it does not, but shows a duration nearly 50% longer, it is possible that the correct interpretation is to divide the sound into two segments on the basis of a "pattern-matching" criterion. Since the acoustic wave is ambiguous in this area, how is it possible to determine the transition, if one exists, between the vowel and liquid segments? Obviously, the English language requires both segments involved in this vowel on independent grounds, e.g. both sounds are found without the other. Therefore, admitting the phone /ɚ/ to the inventory increases the number without increasing the possible combinations. Because both sounds are independently motivated, which could make it difficult to get native speakers' judgements on the one or two segment nature of the sound, we must turn to other methods of determining the probable answer. In this respect, we can measure examples of the sounds when occurring separately and when together, then compare the durations. On the assumption that they are independent, the duration of /ɚ/ should equal that of /ə/ + /r/. Another approach is the one taken here. As unstressed vowels have shown a fairly consistent duration of about 60 msec. in several studies (Klatt, 1979; Krishnan, 1983), it is likely that this duration reflects an accurate value. Therefore, it makes the 96 msec. average duration of the /ɚ/ vowel unlikely and supports the interpretation that it is actually composed of two segments with an indefinite boundary.

G. Subject Grouping

To further investigate why the two languages were significantly different, the averages for each foot, for each subject and for each subject's feet were plotted using inter-stress interval 1, total vowel and consonant 1 values (see Figures 8 to 16). Not surprisingly, the languages are clearly differentiated both by overall mean (collapsed across subjects), as well as by individual subject means. Even the data for each subject's foot means, collapsed across tokens, show a grouping that consistently argues against classifying the two languages as similar.

The first graph plots inter-stress interval 1 against total vowel duration (see Figure 8). French shows a linear relation, indicating that ISI1 and total vowel duration grow in proportion, while English demonstrates less growth in vowel duration until foot 3 and then shows a greater increase than does French. The French data appear, therefore, to confirm the idea of syllable-timing, demonstrating a ratio of inter-stress interval to vowel duration. However, the calculation of this type of comparison seems complicated for a listener to use while simultaneously listening to and understanding the communication. While some sort of duration estimation must take place (e.g. Huggins, 1978; Ventsov, 1981), any involved analysis will require that a listener either expend more effort on fixing the duration of the elements involved (whether segments, clusters or syllables) or have an automatic mechanism for deciding if sections of speech are of the same duration. Since both of these approaches introduce complexity, it would be preferable to have an analysis which could provide the correct results without needless, or, at least, new, concepts. An extra caution is that finding a measure which lends credence to syllable-timing does not mean that syllable-timing is real, in the sense that it can be perceived independently of homo sapiens. This is especially so as the English data show no support for stress-timing. Once again, the paradox is that

Figure 8 — ISI1 by Vowel Duration (Languages)



while one hypothesis could be supported, the other is not.

The subjects' average means, pooled across tokens and feet, clearly show that the French subjects had, overall, longer durations for both ISI1 and total vowel duration (see Figure 9). This runs counter to Dauer's (1983) suggestion that languages have the same inter-stress interval, with the language structure accounting for the perceived differences. If this were the case, the subjects should be randomly dispersed around one central tendency, not split into two quite separate groups. However, any two groups, even if identical in overall performance, can be expected to attain different measures on any one sampling. It is possible that the difference we see in Figure 9 is related to this variability of means.

Figure 10, showing averaged ISI1 and V1 collapsed across tokens, is more complex due to both the number of data points present and the increasing dispersion of the foot by language groups as foot size increases. While foot 1 is compactly grouped, the utterances for foot 5 cover a wide territory. One thing which is apparent from this figure is that the variability of the French subjects around the average value is much higher than that of the English subjects. Not being aware of any explanation for this in terms of language, I assume it is attributable to the subject sample. Especially as Grosjean & Deschamps (1972, 1973, 1975) found their French subjects to use longer breath groups and, therefore, fewer pauses than their English

Figure 9 – ISI1 by Vowel Duration (Subjects)

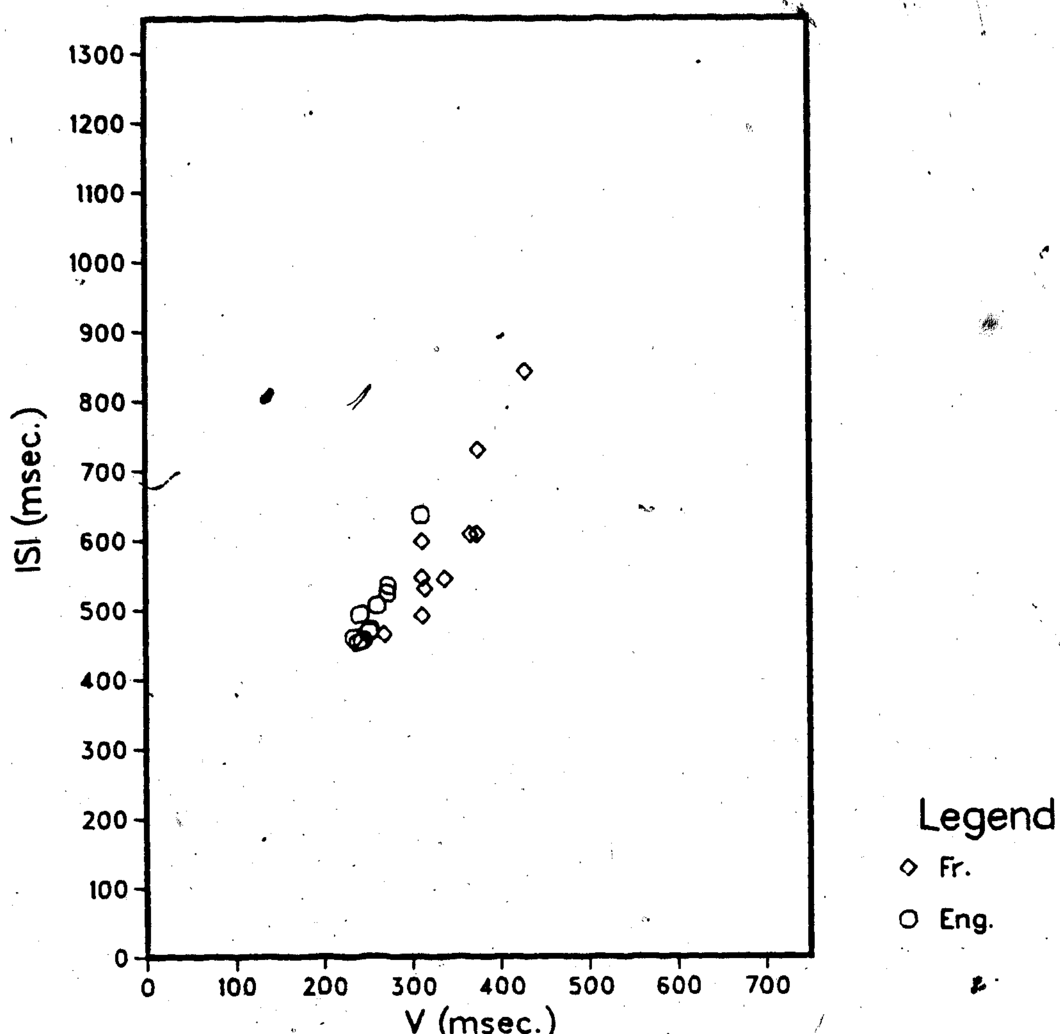
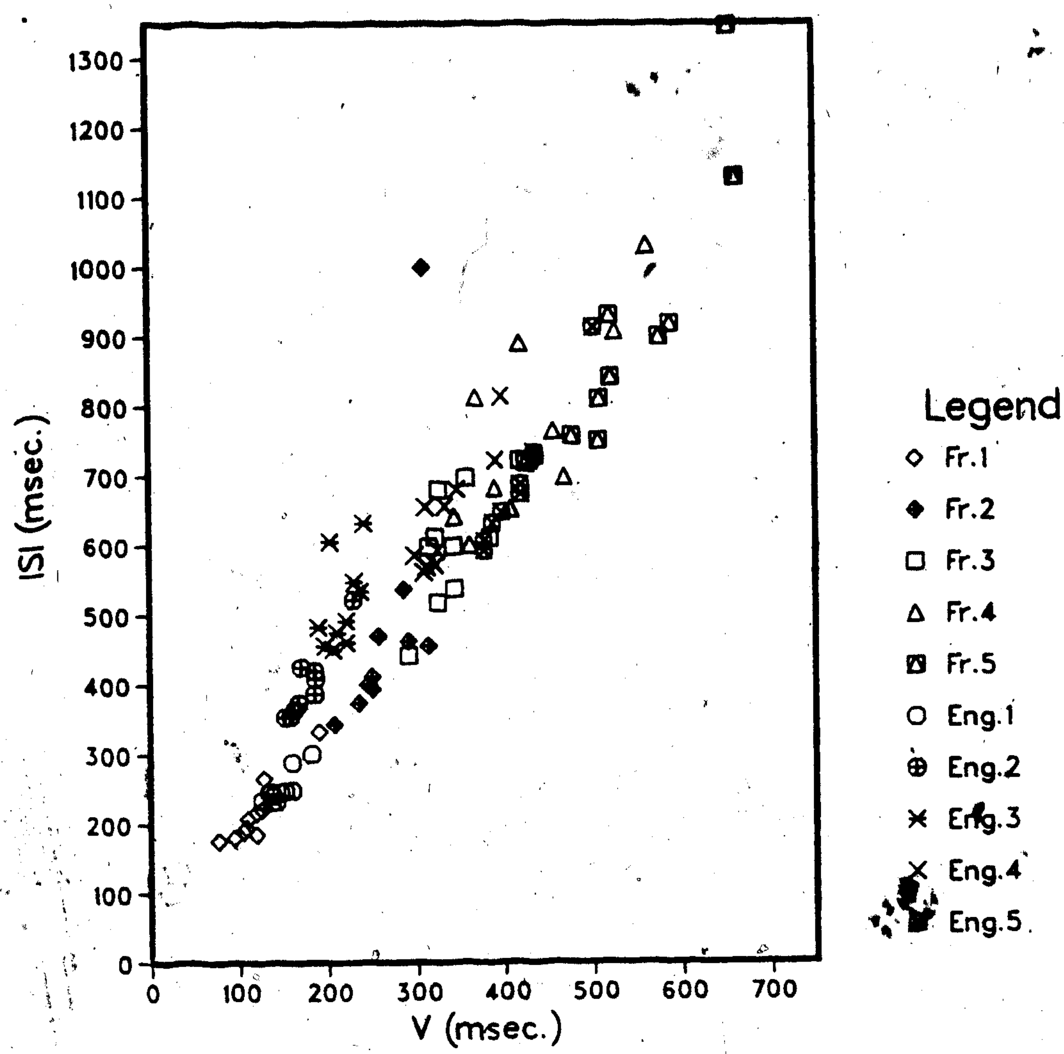


Figure 10 — ISI1 by Vowel Duration (Feet)



subjects, while maintaining a similar speech rate.

Figures 11 to 13 for ISI1 by consonant 1 show a similar result to the previous three. Again, the French subjects show a linear relationship between ISI1 and C1 while the English subjects show a large increase in C1 for feet 1 to 3 followed by a decrease in feet 4 and 5. This is the opposite of the vowel data, which shows why the inter-stress interval is more consistent than either of its two main components, vowel and consonant duration. However, the French subjects show evidence of all three components being more like a linear composition.

Figure 12 , with the subjects' individual means, shows again that the grouping is clearly by language. This time, the French subjects show shorter consonant duration than the English though, which could indicate a trade-off by maintaining a longer duration for the vowels in the inter-stress interval at the expense of the co-occurring consonants. While it has been claimed that English tends to reduce the duration of vowels more than consonants as speech rate increases (Port, 1981), the opposite tendency, of not reducing vowels but shortening or eliminating consonants, has been proposed for syllable-timed languages (Dauer, 1983).

The subjects' average durations for ISI1 and C1 collapsed across tokens (see Figure 13) show very similar results to that of ISI1 and V1. The cohesive grouping of subjects by languages dissipates as inter-stress interval

Figure 11 — ISI1 by Consonant Duration (Languages)

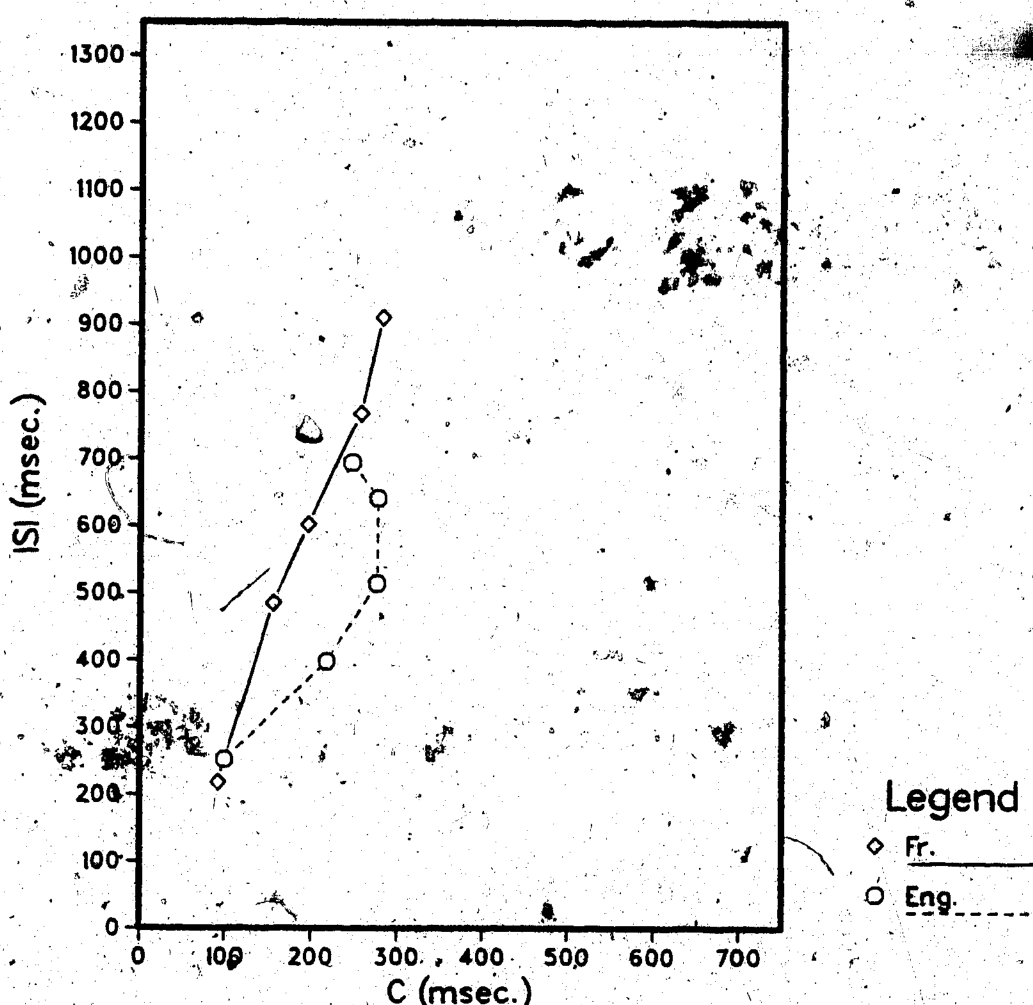


Figure 12 — ISI1 by Consonant Duration (Subjects)

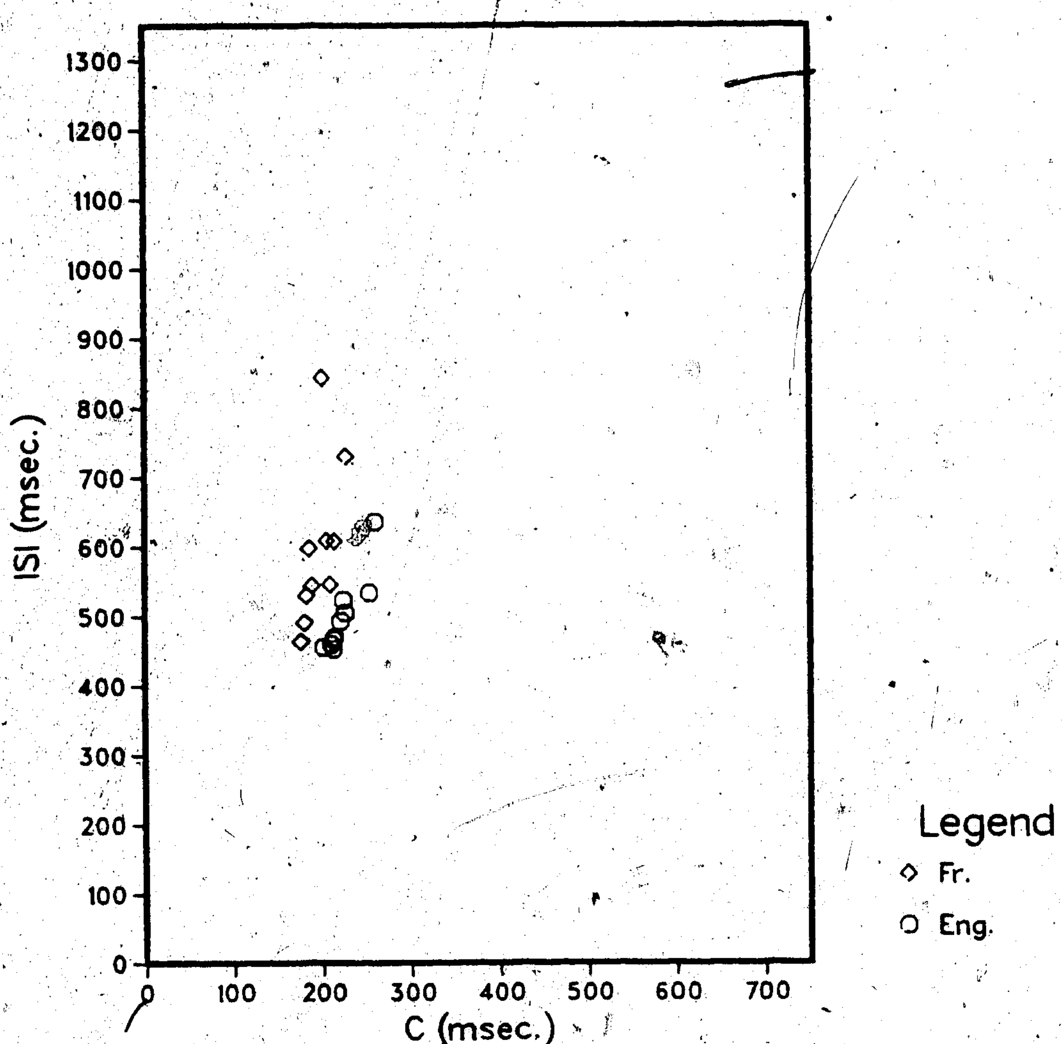
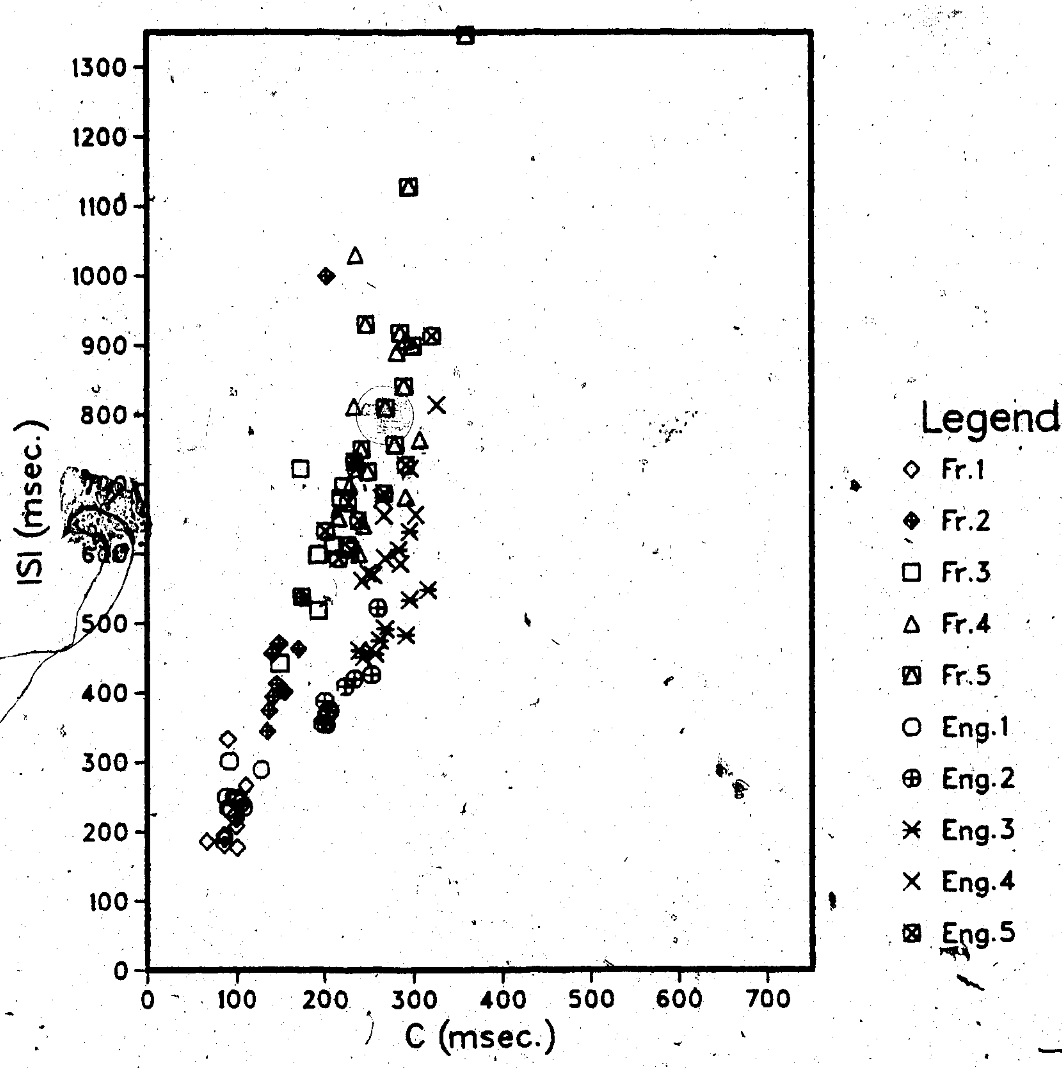


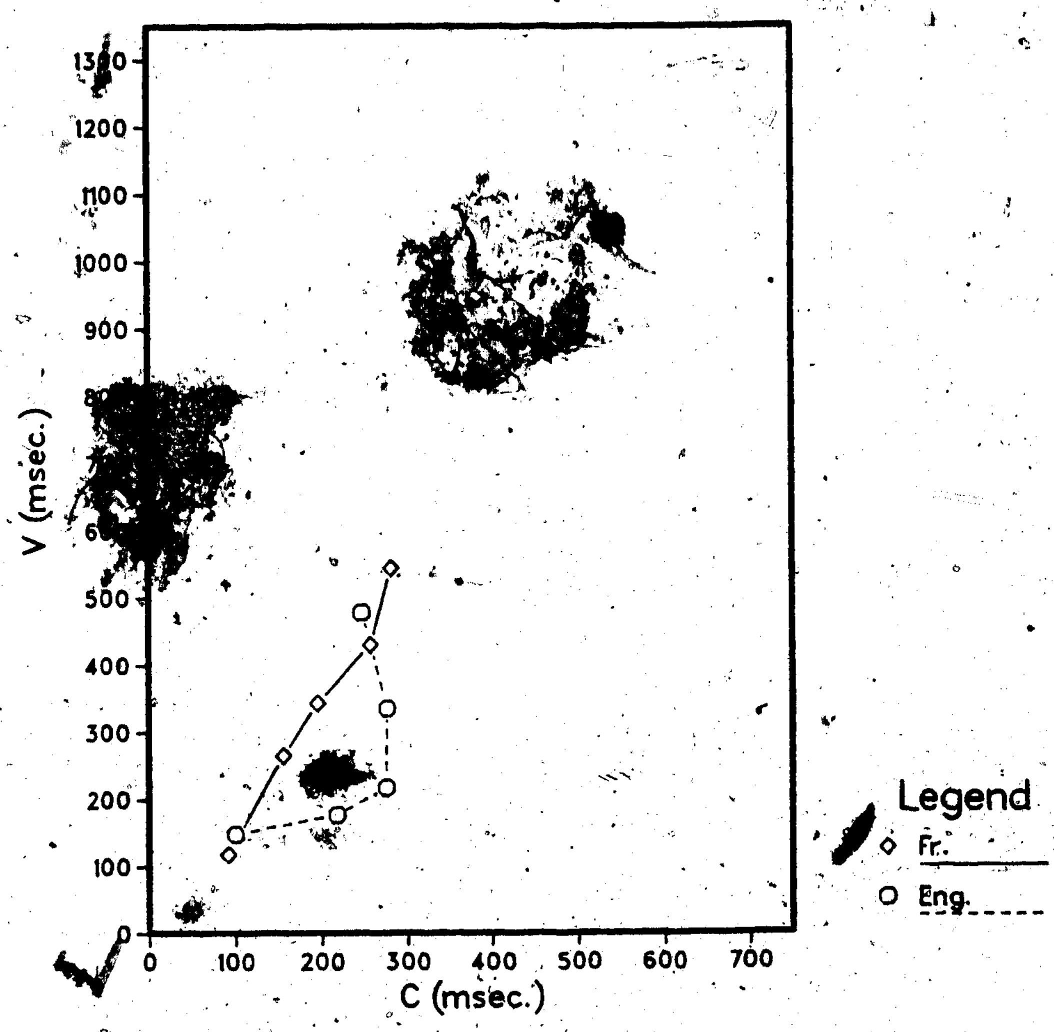
Figure 13 — ISI1 by Consonant Duration (Feet)



increases, but C1 duration seems to have less spread in the subjects' values. Of course, one ready answer for this is the large difference in average duration for the two values- ISI1: 548.0 msec. and C1: 210.1 msec. For this reason alone, the variation is decreased for C1. Another factor is that ISI1 also includes pauses and/or repetitions, which would inflate the durations reported, as well as increase variability among subjects. This is due to subjects having average pause durations of from 0 to 224.3 msec. This figure shows a more compact grouping for all subjects than does Figure 10, which indicates a greater variation in vowel duration than consonant duration. This supports Klatt's (1976) contention that vowels are more affected by rate and stress changes than consonants by indicating that subjects, who use different speaking rates, show less variation in consonant than vowel duration.

Figure 14, showing means averaged over tokens and subjects, clearly shows that the English and French subjects do not treat V1 and C1 similarly. Interestingly, both groups have the same foot 1 values, and English foot 5 and French foot 4 share the same durations. Other than that, the values diverge much more than the other factors we have been examining. Again, this presents an argument in favour of Dauer's (1983) hypothesis, that the language structure differentiates languages and not their timing patterns. We have seen that the figures based on inter-stress interval show more similarity, yet the inter-stress interval is made

Figure 14 — Vowel by Consonant Duration (Languages)



up of these two components, plus the pause time. For the divergence of these two factors to be cancelled out, to some extent, when they are added together indicates that the two subject groups share a common strategy for overall timing, with a much greater variation among the separate components.

The subjects' average durations (see Figure 15) also point out the clear grouping by language. This does not differentiate the V1 by C1 analysis from the preceding two, as all three show an obvious separation. However, the other two are most clearly separated by ISI1, which, as we have already seen, is a component which lends itself to such differentiation more strongly. These figures have an elongated shape, whereas this figure has a fairly compact shape. Further, the two languages are clearly separated in dense aggregations about their respective means. In part, this can be attributed to the shorter duration of the two components being plotted. As speech is a motor activity (Allen, 1975), its variability is expressed as a percentage. This means that longer durations will entail greater variation. When this is combined with the lack of pause duration in the V1 by C1 graph, it explains most, if not all, of the reduction in variation among subjects.

In Figure 16, it is obvious that the coherence in the grouping for individual subjects' durations has increased. Both languages and foot size display clear influences, as opposed to the intermingling which becomes obvious as foot size increases in Figures 10 and 13. Also, the linear trend

Figure 15 – Vowel by Consonant Duration (Subjects)

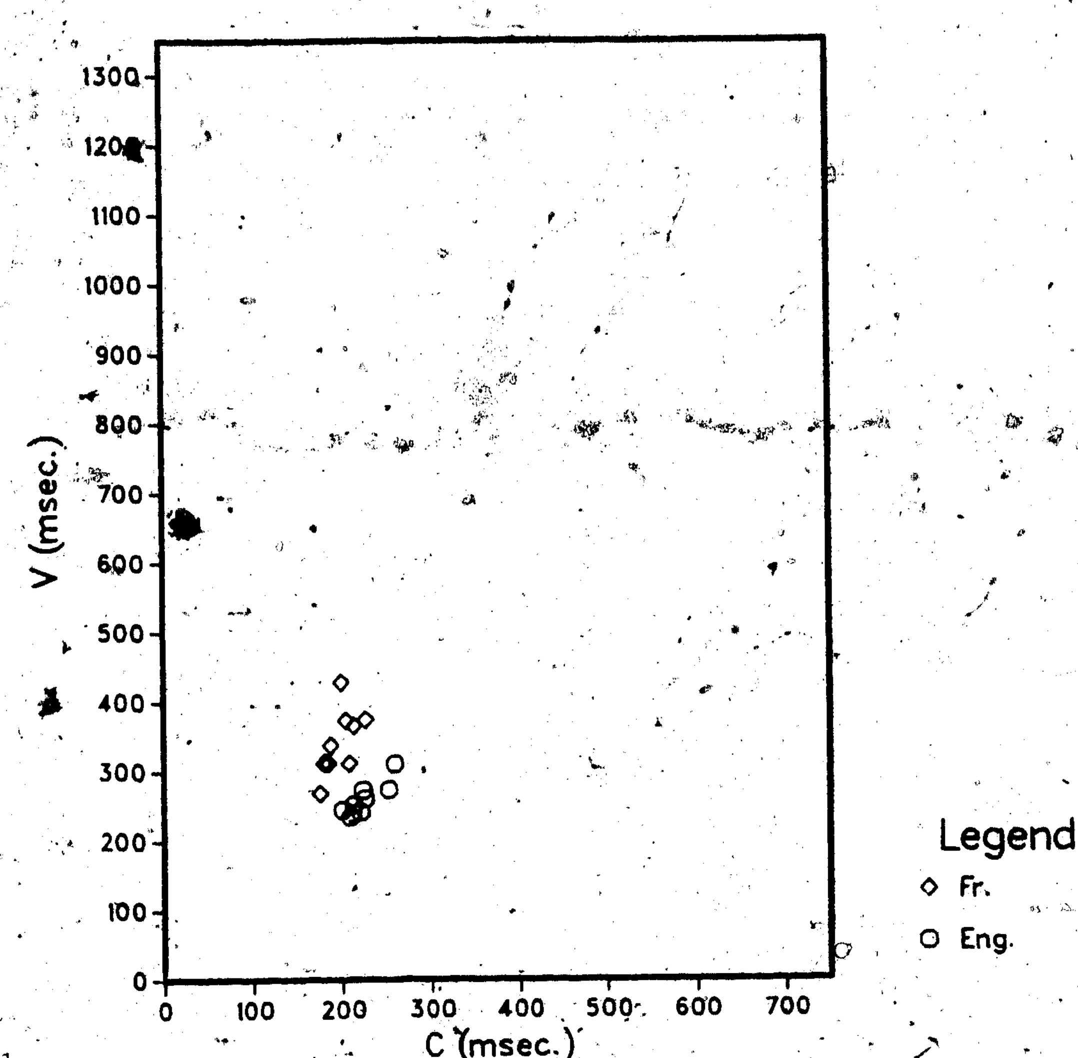
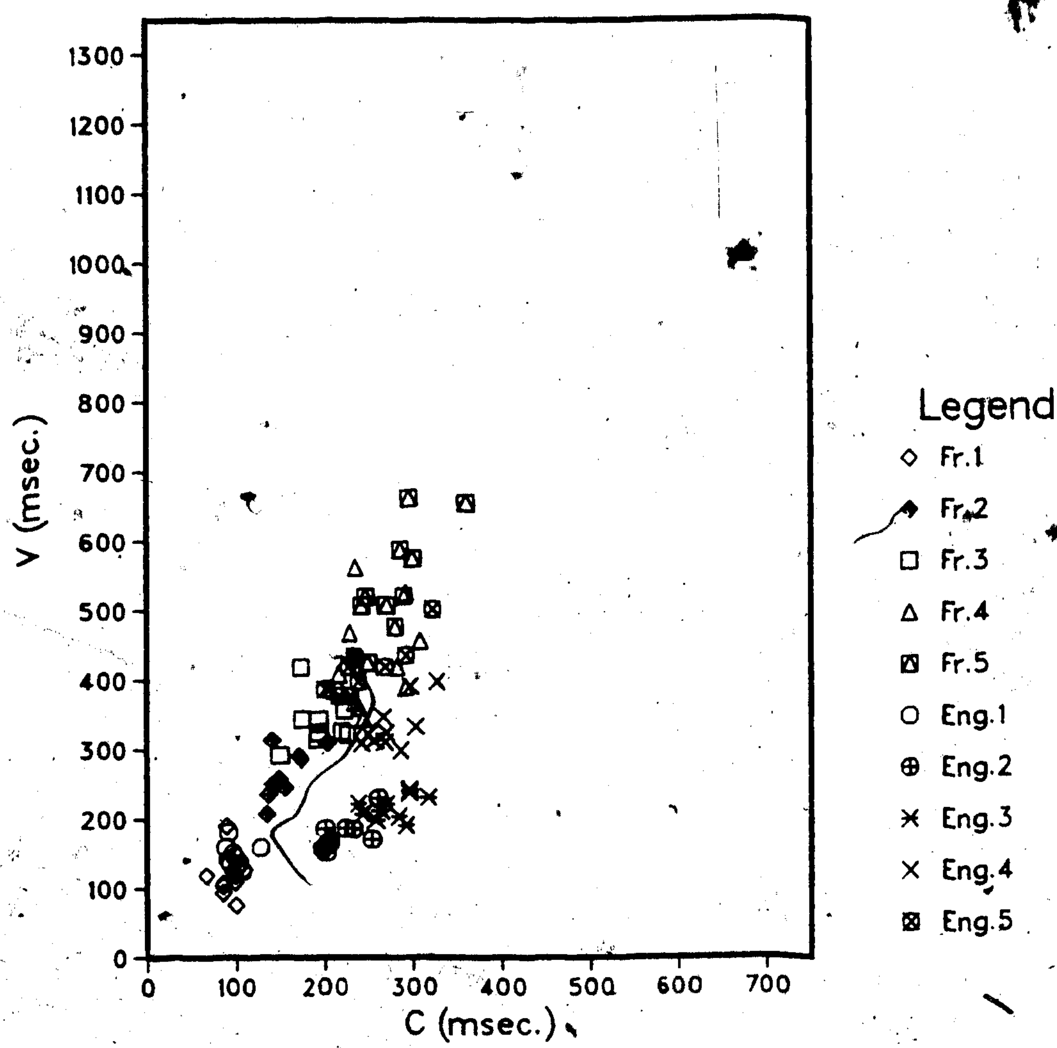


Figure 16 – Vowel by Consonant Duration (Feet)



for the French subjects retains a clear effect in the data. It seems reasonable to use a linear exponent for the French data, as the duration from the theoretical line is far less than is evident in the other figures. For English, the interesting point is that the general trend could be interpreted as showing stress isochronicity. At first, the vowel duration increases by a smaller amount than would be anticipated. When this is no longer possible (e.g. Klatt's (1976) incompressibility hypothesis), the consonant duration takes over and aids the struggle to stop the inter-stress interval from growing.

H. Ratios

Part of the problem with interpreting the ratio analyses of the data is that the shape the graphs would need to take to demonstrate syllable and stress isochronicity is unclear. No one has defined these hypotheses clearly enough in terms of their components to enable us to know what relationships to look for. For example, in a syllable-timed language, would all syllables share a constant ratio of vowel to consonant as well as a common duration? This, of course, then enters the area of segmental duration as Klatt (1976) estimated that what he called "inherent phonological duration" accounts for 50% "of the variance in stressed vowel durations in a connected discourse." [16] This is further backed up by Hill, Witten & Jassem (1978), who found

[16] Klatt (1976), p.1213.

phoneme type to govern 45% of the overall variance in segment duration for English.

For stress-timing, this lack of clarity is more profound as the inter-stress interval itself, while being maintained to be a constant duration, has never had this duration specified. In fact, the only measurement that seems appropriate with the data collected here, 499.7 msec., the average ISI1 duration, is only slightly shorter than foot 3, and would mean foot 1 would have to be double its measured duration in order to fit. This duration is further supported by the lack of any apparent isochronicity from foot 1 to 3, which could indicate a shorter value. Since we are not told what effect fitting different feet into the inter-stress interval will have nor what duration the inter-stress interval is, it is impossible to determine whether the ratios presented here a[illegible]with those predicted by the theory. One way to illustrate that these measurements show no sign of stress isochronicity is to choose a measure which maintained a consistent duration across the feet, such as first unstressed vowel, shown in figure 6(e). Under the assumption that the inter-stress interval was also constant, this figure would be a straight line across the plot. Another effect of stress isochronicity would be to render these graphs as illustrations of the variance of the inter-stress interval component being plotted. Comparing figure 6(b), which shows stressed vowel/inter-stress interval, to figure 4, with stressed vowel duration alone, it is obvious that more than the component is changing.

VI. CONCLUSION

The results of this study show little comfort for those who maintain the distinction between stress- and syllable-timing. Comparing the observed data with the data predicted by the isochronic hypotheses, it is obvious that neither hypothesis accurately describes the speakers' utterances. In view of the number of studies which have found similar results, it is clear that if isochrony exists in language as it is produced in real time, it is covered by layers of other constraints which cloak its true aspect. Therefore, I consider these two concepts not to be appropriate descriptors of a language process. For an hypothesis to have validity, it must come to light in some statistically significant way in the course of investigation-. In the only study I have found which attempts to give a defined quantity to the tendency towards stress isochrony in English (Hill, Jassem & Witten, 1978), the authors claimed that it accounts for 9% of the variance in segment length\. While such a figure may be low, it does not seem too much at odds with the data reported here. If such a breakdown is true, why should we group languages by a factor which is so minimal in relation to overall timing constraints?

At the base of stress and syllable isochrony is the assumption that timing patterns in language are malleable and subject to modification. In order for this to occur, the underlying muscle contractions would also need to be reorganized. One question which has not been addressed is how such a massive change could take place. Is it reasonable to expect that a child learning English will start with a syllable-timed pattern and change to a stress-timed one automatically after a certain amount of practice and/or exposure (Allen & Hawkins, 1978)? How can we explain a Brazilian Portuguese speaker who shows indications of using syllable-timed speech in citation and stress-timed in casual speech (Major, 1981)? Obviously, this kind of change in motor commands can be achieved, but it is not the most attractive explanation, especially when we consider that an alternative exists which allows an explanation of both phenomena without recourse to alteration of timing control inside the central nervous system and brain.

As a further example, Dauer (1983) claimed that all the languages he studied showed a consistent inter-stress interval of 500 msec. Because his figures match those of other investigators (Borzone de Manrique & Signorini, 1983; Uldall, 1971) as well as other evidence of human rhythmic activity (Allen, 1975; Lenneberg, 1967), this inter-stress interval of 500 msec. is well attested. When we consider how stress- and syllable-timing would achieve an average duration, it is obvious that they cannot relate to similar lines of motor control. A stress-timed language would use a fixed inter-stress interval (presumably, 500 msec.), requiring a Procrustean interface to squeeze up or stretch out the syllables to fit the time allotted. Syllable-timed languages, however, would depend on an averaging of the durations of the actually occurring inter-stress intervals, as the ISI would depend on the number of syllables present. Such arrangements would require a method of adjusting the speed of the articulators depending on the foot size in English, with no concurrent adaptation in French. While this would explain the apparently more limited range of English feet, compared to French and Spanish, it raises many more questions. How can we explain a difference in underlying motor commands which correlates to language? And how can a person learn a language with a different type of timing than that of the native language?

This brings up the question of how timing control in speech is maintained. That speakers can control timing is beyond question - individuals possess an idiosyncratic speech rate, yet can speed up or slow down their output within a limited range. If this timing were located in a device external to the speech process itself, the coordination required with the language source would be immense, in order to account for variation such as long versus short vowels or differential shortening of segments and/or syllables as rate increases. Although hypothesizing different layers of timing control could account for this result, such that there are different mechanisms which account for segment, syllable and inter-stress duration, allowing each level to be adjusted in a nested fashion, the control required to implement speech could quickly become impossible to exercise. When we consider how easily people can produce speech, even while engaged in other complex tasks, it seems apparent that not only practice is involved in explaining how the timing arises. It is possible that some form of top-down processing could explain how all the different layers of language interact to produce the observed result, but such a procedure seems doomed to hopeless complexity.

I do not maintain that elegance, or even lack of complexity, is required of any theory dealing with people's abilities. There is ample evidence to suggest that we are not bound by minimal complexity and simple functioning in our more conscious activities, such as choices between a multitude of options or attempts to optimize our work habits. However, there is an upper limit to the complexity of a situation which we can handle in a small amount of time. Although we can choose our ten favourite record albums of all time over a period of a few weeks, making the same choice in ten minutes would doubtless result in a different list. So, I do not argue that a solution to human behaviour must be put aside because it is complex. By breaking down a complex proposition into simpler components, we can analyze each section independently and obtain the result. The catch comes when we wish to obtain this result in a short space of time. Even under the assumption that, as a child learns a language, it also learns to automate a certain portion of the actions, phrases and responses used, a large chunk of language is still left open as creative, non-repetitious, unrehearsed speech. It is in these cases that the constraints imposed by a complex operation are at their maximum. Evidence from stutterers indicates that, when uttering rehearsed lines, as in singing or acting, there is no interference with the speech process. When the same people attempt to produce novel utterances, however, they stutter (Healy, Mallard & Adams, 1976). This would indicate that a reading task, as used here, should give subjects a better chance to display the constraints imposed by the languages themselves and discard the production constraints on novel utterances. Even in a situation as relaxed as this, some subjects found it difficult to reproduce the text given to them, as is evidenced by the large amount of pause time. One French subject showed a decrease of 224.3 msec. in average inter-stress interval as a result of removing the pauses. This is roughly the average for foot 1! These difficulties with reading a text can, of course, arise due to limitations in other systems, such as faulty vision. No matter, pause time is an essential ingredient of language, even when strategically located at segment boundaries, as people need to breathe in order to speak. And this coordination adds another layer of complexity to the speech act, as well as to its analysis.

I believe that stress and syllable isochrony, as explanations for the perceived differentiation of spoken language, are incorrect. While the English and French speakers tested show clearly that the languages do not treat the defined inter-stress intervals in an equivalent manner, a theory which claims the syllables are of equal duration in French is as patently wrong as one for inter-stress intervals of equal duration in English. The data do not support such an interpretation. Certainly, we can argue that French shows a greater tendency towards syllable-timing, as does English to stress-timing. The only problem with such a response, is that it raises more questions than it answers. At the very least, we need a definition of tendency which can support further research before we can accept it; i.e. what percentage of this tendency is required before a language can be called either stress- or syllable-timed? If, on the other hand, we relegate isochrony to the perceptual domain, we need some explanation of how speech is timed in production. Perhaps syllable and stress isochrony refer to a phenomenon which relates to the interaction of speech production and perception. Clearly, the data indicate that neither hypothesis accurately describes the measured durations of the subjects. The gap between predicted and observed results is simply too large to be ignored by either experimenters or listeners.

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Appendix A

English - Firefighting Text

Once a forest fire is reported the firefighting strike force takes to the air. The fire-bombing tankers can be immediately called into service by the regional conservation society and used to mount an initial assault on the fire before it has had a chance to spread, and before the ground crews arrive. Some fires would be difficult to contain if it were not for these tankers, which are accompanied by a rapid twin-engine aircraft capable of speeds of up to 300 kilometres per hour and designated as the tracker aircraft with a firefighting expert on board. Aerial tracking is a radio communications system for guiding tankers and ensuring coordination between aerial firefighters and ground crews under conditions of maximum safety.

Helicopters are also useful because of their versatility and ability to perform highly specific tasks. In addition to scouting fires they are used in the transportation of firefighters and supplies. They also carry crews to areas on the perimeter of major fires to put out "spot" fires, isolated outbreaks detected by infrared Thermo-Vision scanners.

But, however spectacular the air attacks are, they alone cannot take on a forest fire. The battle must also be engaged from the ground: indeed it is the ground crews that are primarily responsible for bringing the fire under control. The head of the ground crews directs operations. He determines the size and direction of the fire, and the speed at which it is spreading, then sends his men ahead to make a firebreak by denuding the area of all combustible material on which the fire might feed. This firebreak is created with hand tools or heavy machinery such as fire plows or bulldozers; back-up comes from portable motor pumps that take enough water from nearby streams or lakes to drench the ground and stop the fire from spreading. The final step, once the fire has been contained, is to ensure that the fire cannot start up again or continue to smoulder for a few days and then flare up again with renewed vigor. Ground crews therefore go over the forest floor and area again with hoses making sure that every pocket of flame is well and truly extinguished.

<u>English - Train Text</u>

I had the train compartment to myself up to Rohana, and then a girl got in. As I had become blind, my eyes sensitive only to light and darkness, I was unable to tell what the girl looked like. But I knew she wore slippers from the way they slapped against her heels, and I liked the sound of her voice.

"Are you going all the way to Dehra Dun?" I asked.

I must have been sitting in a dark corner, because my voice startled her. She gave a little exclamation, and said "I didn't know anyone else was here."

I wondered if I would be able to prevent her from discovering that I couldn't see. I thought: Provided I keep to my seat, it shouldn't be too difficult.

The girl said, "I'm getting off at Saharanpur. My aunt is meeting me there. Where are you going?"

"To Dehra Dun and then to Mussoorie," I answered.

"Oh, how lucky you are! I wish I were going to Mussoorie. I love the hills. Especially in October."

"Yes, this is the best time," I said, calling on my memories. "The hills are covered with wild dahlias, the sun is delicious, and at night you can sit in front of a log fire and drink a little brandy. Most of the tourists have gone, and the roads are quiet and almost deserted."

Then I made a mistake. "What is it like outside?" I asked.

She seemed to find nothing strange in the question. Had she noticed already that I could not see? But her next question removed my doubts.

"Why don't you look out of the window?" she asked.

The window was open, and I faced it, making a pretense of studying the landscape. "Have you noticed," I ventured, "that the trees seem to be moving while we seem to be standing still?"

"That always happens," she said.

I turned from the window and faced the girl, and for a while we sat in silence. "You have an interesting face," I said.

She laughed pleasantly, a clear, ringing laugh. "It's nice to be told I have an interesting face. I'm tired of people telling me I have a pretty face !"

Oh, so you <u>do</u> have a pretty face, I thought, and aloud I said: "Well, an interesting face can also be pretty."

"You are very gallant," she replied. There was a pause. And then she said, "Thank goodness it's a short journey. I can't bear to sit in a train for more than two or three hours."

The engine's whistle shrieked, the carriage wheels changed their sound and rhythm. The girl got up and began to collect her things. I wondered if she wore her hair in a bun, or if it was plaited, or if it hung down loose over her shoulders, or if it was cut very short.

The train drew slowly into the station. Outside, there was the shouting of porters and vendors, and a high-pitched female voice near the carriage door which must have belonged to the girl's aunt.

"Good-by," said the girl.

There was some confusion in the doorway. A man getting into the compartment stammered an apology. Then the door banged shut, and the world was closed out again. I returned to my berth. The guard blew his whistle and we moved off. I found the window and sat in front of it, staring into the daylight that was darkness for me. The man who had entered the compartment broke into my reverie.

"You must be disappointed," he said. "I'm sorry I'm not as attractive a travelling companion as the one who just left!"

"She was an interesting girl," I said. "Can you tell me - did she keep her hair long or short?"

"I don't remember," he said. "It was her eyes I noticed, not her hair. She had beautiful eyes, but they were of no use to her - she was completely blind. Didn't you notice?"

French - Firefighting Text

Lorsqu'un incendie de forêt est repéré, la lutte débute du haut des airs. La Société de conservation peut faire appel immédiatement aux avions-citernes, dont l'utilisation a pour but de faciliter l'attaque initiale des incendies pendant qu'ils sont encore de dimensions réduites. En attendant l'arrivée des équipes au sol, les avions-citernes commencent la lutte qu'ils appuieront par la suite jusqu'à ce que l'incendie soit contenu. Sans ces avions-citernes, certains incendies pourraient difficilement être combattus. Ces avions-citernes sont accompagnés d'un bimoteur rapide (300 km/h) désigné sous le nom d'avion d'aéropointage, à bord duquel prend place un expert dans la lutte contre les incendies forestiers. L'aéropointage est une technique de guidage des avions-citernes visant à assurer, par les communications-radio, une bonne coordination de la lutte aérienne avec la lutte au sol, tout en garantissant la sécurité de l'opération.

Enfin, des hélicoptères, en raison de leur grande aptitude à répondre à des besoins spécifiques, servent á diverses tâches de transport de matériel et d'équipes, au repérage et également à l'observation des incendies; ils sont en outre utiles pour le déplacement, sur le périmètre des grands incendies, des équipes de suppression des fumées isolées, détectées à l'aide d'un appareil à infra-rouge appelé "thermo-vision".

Le combat contre le feu est également mené au niveau du sol. C'est d'ailleurs à l'équipe au sol que revient le principal rôle de neutralisation de l'incendie. Car, toute spectaculaire qu'elle soit, l'utilisation des avions-citernes ne peut, à elle seule, permettre de vaincre un incendie de fôret. Le chef de lutte de l'équipe au sol prend charge des opérations. Après avoir évalué l'ampleur, la direction et la vitesse de propagation de l'incendie, il déploie ses hommes dans un secteur où se dirige le feu, afin d'y effectuer un coupe-feu qui consiste à éliminer tout "aliment" combustible dont pourrait se nourrir l'incendie. Le coupe-feu est réalisé à l'aide d'outils manuels ou de machineries lourdes comme les béliers mécaniques (bouteurs). Et des motopompes, s'alimentant à même un cours d'eau voisin, serviront à acheminer en bordure du foyer d'incendie des milliers de gallons d'eau qui détremperont le sol à un point tel que le feu ne pourra s'y propager. Une fois l'incendie ainsi circonscrit, une dernière étape reste à accomplir. Afin d'éliminer tout risque ultérieur de reprise de l'incendie, l'équipe au sol arrose copieusement chaque petit foyer qui subsiste, car le feu pourrait couver pendant plusieurs jours et se propager de plus belle. Quand l'équipe au sol quitte finalement les lieux, l'incendie est bel et bien éteint.

French - Train Text

Jusqu'à Rohana, j'étais seul dans mon compartiment. Mais voilà qu'une jeune femme vient d'y pénétrer. A quoi ressemble ma compagne de voyage? Je n'en sais rien. Devenu aveugle, je ne distingue plus que les alternances de lumière et d'ombre. Mais au léger claquement de ses chaussures contre ses talons, je devine qu'elle porte des sandales. Et j'aime bien le son de sa voix.

"Allez-vous jusqu'à Dehra Dun?" dis-je.

Sans doute ai-je choisi un coin bien obscur pour m'asseoir, car elle sursaute et s'exclame:

"Je ne savais pas qu'il y avait déjà quelqu'un dans le compartiment!"

Serais-je capable de lui dissimuler ma cécité? Si je me contente de rester assis, cela ne devrait pas être impossible, après tout.

"Je m'arrête a Saharanpur, reprend la jeune fille. Ma tante doit venir me chercher à la gare. Et vous?

-Je vais à Dehra Dun, puis je continuerai sur Mussoorie.

-Oh! vous en avez de la chance! J'aimerais tant aller à Mussoorie, Les collines y sont si belles en octobre.

-Oui, c'est vraiment le meilleur temps de l'année, dis-je, m'enhardissant à évoquer mes souvenirs. Les collines embaument le dahlia sauvage, et le soleil est d'une tiédeur délicieuse. Le soir, on s'installe près du feu pour siroter un brandy. La majorité des touristes sont partis, les routes sont tranquilles, presque désertes."

Et alors, je commets une sottise:

"Dites-moi, est-ce que c'est beau dehors?"

Elle ne paraît pas s'étonner de ma question. A-t-elle percé mon petit jeu? Sa réponse, en forme de question, me soulage.

"Pourquoi ne vous approchez-vous pas de la fenêtre?"

Le visage tourné vers la fenêtre ouverte, je fais mine de scruter le paysage.

"On dirait que ce sont les arbres qui se déplacent et pas nous. Avez-vous remarqué?

-C'est toujours comme ça", observe-t-elle.

Je me tourne vers elle. Pendant un bon moment, nous restons sans parler. Enfin, je hasarde: "Vous avez un visage intéressant."

Elle a un rire léger, clair et sans affectation.

"Voilà qui me change agréablement des banalités habituelles. J'en ai assez de me faire dire que je suis jolie!"

Donc, vous êtes jolie, me dis-je en moi-même, avant de répliquer:

"Un visage intéressant peut aussi être beau.

-Vous êtes très aimable."

Le silence retombe. Cette fois, c'est elle qui renoue le fil de la conversation: "Dieu merci, le voyage n'est pas long. Après deux ou trois heures dans un train, je ne tiens plus en place."

Le train siffle à en déchirer l'air. Sous nos pieds, les roues ne marquent plus le même rythme. Ma compagne s'est levée et déjà s'apprête à partir. J'aimerais bien savoir comment elle est coiffée. A-t-elle les cheveux longs ou courts? Remontés, nattés ou dénoués?

Le train ralentit davantage, s'immobilise. Sur le quai, le long de notre wagon, une voix de femme haut perchée se mêle aux cris des porteurs et des vendeurs. Sûrement la tante.

"Au revoir", fait la jeune fille.

Il semble y avoir une petite bousculade à la porte. J'entends une voix d'homme qui bafouille des excuses, puis le nouvel arrivant referme la porte derrière lui, réduisant le brouhaha de la gare à une faible rumeur. Au coup de sifflet du chef de gare, nous redémarrons.

Assis à la fenêtre, le visage tourné vers l'extérieur, je contemple l'éternelle obscurité qui me masque le jour. Mon nouveau compagnon fait une remarque qui me tire de ma songerie.

"Vous devez bien être un peu déçu. Comme compagnon de voyage, je ne vaux sûrement pas la ravissante jeune femme qui vient de descendre!

-Elle était charmante. Dites-moi, avait-elle les cheveux longs ou courts?

-Ça, je n'en sais rien, me répondit-il d'un ton intrigué. Je n'ai pas remarqué ses cheveux, seulement ses yeux. Superbes, mais tellement inutiles! Elle est aveugle, la pauvre. Ne l'avez-vous pas remarqué?"

Appendix B

Sampling Programme: Gee

```
C
C TO SAMPLE FROM TAPE RECORDER
C AND RECORD ON MINGOGRAPH
C
  CLEAR ALL
  LABEL 1
C
  DATA Y
  DATA T
  DATA SEG*8
C
  READ *TTY &SEG
  SET NTH=32
  SET FREQ=8
  SET SDIAL=3
  SET SCROLL=ON
  LABEL 0
  CONTROL TR:PLAY
  IF #SS:5 EQ 1 GOTO 0
  SAMPLE
  CONTROL TR:STOP
  P
C
  ED
  LABEL 2
  LOCK
  WAIT 3SEC
  IF #SS:1 EQ 1 PCURSE
  IF #SS:2 EQ 1 PLAY
  IF #SS:0 EQ 1 GOTO 2
  EX &SEG
  RETURN
C
  QUE &SEG
  MEAS DUR &Y &T
  PRINT &Y &T
  SET FMODE=ON
  CALP
  SYMBOL 100 512 6 H TURN MINGOGR
  APH ON
  SET FREQ=1
  WAIT 5SEC
  PLAY
C
  WAIT 1SEC
  DWA &SEG
  GOTO 1
  END
END OF FILE
```

Display Programme: Sig

```
C
C TO BRING SIGNAL FROM DISK
C
  CLEAR ALL
C
  SET VI=600
  DATA X 0
  DATA Y 16
C
C DO NOT FORGET TO PUT DISK
C ON WRITE PROTECT FOR SAMA2
C
  $SYS GET 5 0 0 0
C
  SAMPLE
C
  PRINT GIVE ME DISK
  STARTING BLOCK NUMBER
C
  READ *TTY &X
C
  LABEL 0
     $SYS READ &X 20 0 &Y
     ADD &X 16
C
     PRINT &X &Y
     ADD &Y 8
     IF &Y LE 56 GOTO 0
C
     SCALE 1000 511
     PLAY
C
     PR NOW YOU HAVE SIGNAL,
        PRESS SENSE SWITCH 3
     LABEL 2
C
     IF #SS:3 EQ 1 LINK G1
     GOTO 2
     END
END OF FILE
```

Measurement Programme: G1

```
C TO MEASURE TIME SEQUENCES OF
C STUTTERING
C
C
  PR SENSE SWITCH 1 PLAYS
     WHOLE SIGNAL
     SENSE SWITCH 0 PLAYS
     BETWEEN CURSORS
C
  PR BEFORE YOU FINISH LAST
     SEGMENT, PRESS SENSE
     SWITCH 3
C
  DATA Y
  DATA T
  DATA SEG*8
C
  LABEL 0
C
  PR GIVE ME SEGMENT NAME
  READ *TTY &SEG
  SET NTH=64
C
C
C TO EXTRACT SIGNAL FOR MEASURING
C DURATION
C
  EDITOR
C
  LABEL 1
  LOCK
  WAIT 3SEC
  IF #SS:0 EQ 1 PCURSE
  IF #SS:1 EQ 1 PLAY
  IF #SS:5 EQ 0 GOTO 1
  EX &SEG
  RETURN
C
  QUE &SEG
  MEASURE DUR &Y &T
  PRINT &Y &T
  SINK NUMBER *OUT
  WRITE *OUT &SEG &Y &T
  PLAY
  DWA &SEG
  QUE SAM
C
  IF #SS:3 EQ 1 LINK SIG
  GOTO 0
  END
END OF FILE
```

Appendix C

ISI1 Measurements

172	252	256	300	292	207
336	376	516	400	400	428
462	444	504	509	544	488
412	692	593	744	896	600
648	612	568	818	920	764
184	259	243	266	296	245
285	336	602	432	384	482
541	434	524	696	540	472
408	712	550	648	1136	627
640	614	739	748	936	723
152	224	232	248	333	200
204	320	475	381	364	387
440	430	486	535	445	430
395	670	472	524	765	541
480	541	788	1350	613	595
195	321	297	333	359	300
305	393	562	737	696	436
630	471	[illegible]32	763	884	511
755	1114	855	628	933	599
643	661	2040	771	670	692
182	292	308	318	380	254
307	384	528	428	432	474
520	493	542	603	574	555
798	765	553	700	839	680
696	653	720	763	576	713
176	221	245	279	305	222
251	331	419	360	391	372
474	378	407	521	481	477
397	740	474	607	1126	584
559	535	556	686	551	672
171	248	197	279	294	220
277	323	488	389	383	331
429	437	461	1090	755	462
377	771	573	556	669	567
637	586	791	700	758	569
200	252	250	293	296	199
248	334	537	374	398	352
393	434	460	482	476	460
360	653	534	603	706	556
661	571	488	651	729	692
186	227	204	281	332	245
283	360	474	414	384	407
512	469	486	493	430	460
412	693	514	665	650	623
666	592	633	728	636	632
172	218	232	280	273	222
274	338	492	389	356	388
472	404	470	510	585	456
400	757	519	566	676	514
575	600	597	699	601	566

298	252	191	179	244	432
479	500	524	357	525	836
727	437	761	518	512	717
765	616	709	986	895	1368
970	1659	1761	768	1536	1384
299	164	209	163	254	245
409	495	553	308	501	468
774	337	711	488	489	1385
1041	604	721	708	777	732
964	807	893	700	1059	971
226	172	190	179	228	174
466	460	435	266	351	265
664	422	1316	426	718	537
1196	477	657	546	988	1006
736	927	669	603	749	1894
280	198	160	200	251	220
334	432	473	374	443	724
599	333	607	620	485	583
740	620	787	796	796	1701
820	807	941	1080	948	913
259	151	194	170	289	187
323	422	443	767	503	360
704	377	691	485	491	923
763	552	657	678	783	660
623	665	866	816	682	892
556	365	225	234	316	304
614	559	2033	365	1477	947
617	560	783	508	584	1282
1963	556	761	742	906	1250
1175	1019	923	1521	852	1280
248	137	168	141	227	197
384	426	466	295	455	382
588	325	710	512	413	563
630	452	639	608	698	576
703	754	768	741	645	888
234	151	188	150	275	145
398	328	410	346	405	476
640	321	591	442	510	1091
718	619	667	779	678	724
797	726	883	1028	767	843
240	140	151	138	241	150
320	389	400	276	342	337
521	266	531	390	394	548
623	491	577	549	656	949
495	553	690	659	1250	658
233	142	183	154	225	147
276	508	524	299	421	442
574	358	644	423	462	1130
653	436	641	664	760	757
788	743	745	1048	731	802

ISI2 Measurements

172	252	191	300	292	207
336	376	516	400	400	428
462	444	504	509	544	488
412	692	593	744	772	600
648	612	568	818	588	764
184	259	243	266	296	245
285	336	602	432	384	482
541	434	524	696	540	472
408	712	550	648	733	627
640	614	739	748	549	723
152	224	232	248	333	200
204	320	475	381	364	387
440	430	486	535	445	430
395	670	472	524	711	541
480	541	788	1102	613	595
195	161	297	333	359	300
305	393	562	737	513	436
630	471	532	518	569	511
586	948	659	628	933	599
643	661	1042	771	670	692
182	292	308	318	380	254
307	384	528	428	432	474
520	493	542	603	574	555
394	765	553	700	839	680
696	653	720	763	576	713
176	221	245	279	305	222
251	331	419	360	391	372
474	378	407	521	481	477
397	740	474	607	672	584
559	535	556	686	551	672
171	248	197	279	294	220
277	323	488	389	383	331
429	437	461	634	501	462
377	771	573	556	669	567
637	586	791	700	593	569
200	252	250	293	296	199
248	334	537	374	398	352
393	434	460	482	476	460
360	653	534	603	706	556
661	571	488	651	468	692
186	227	204	281	332	245
283	360	474	414	384	407
512	469	486	493	430	460
412	693	514	665	650	623
666	592	633	728	636	632
172	218	232	280	273	222
274	338	492	389	356	388
472	404	470	510	585	456
400	757	519	566	676	514
575	600	597	699	601	566
298	252	191	179	244	267
479	500	524	357	525	379

727	437	761	518	512	620
765	616	709	728	696	690
970	903	1000	768	905	895
299	164	209	163	254	245
409	495	553	308	501	468
774	337	711	488	489	673
1041	604	721	708	777	732
964	807	893	700	918	971
226	172	190	179	228	174
466	460	435	266	351	265
664	422	852	426	366	537
728	477	657	546	662	539
736	638	669	603	749	902
280	198	160	200	251	220
334	432	473	374	443	724
599	333	607	620	372	583
740	620	787	796	796	741
820	807	941	815	948	913
259	151	194	170	289	187
323	422	443	388	503	360
704	377	691	485	491	545
763	552	657	678	783	660
623	665	866	816	682	892
362	241	225	234	316	304
614	559	410	366	430	398
617	560	685	508	410	782
1131	556	761	742	906	685
1063	862	923	908	852	1140
248	137	168	141	227	197
384	426	466	295	455	382
588	325	710	512	413	563
630	452	639	608	698	576
703	754	768	741	645	888
234	151	188	150	275	145
398	328	410	346	405	476
640	321	591	442	510	722
718	619	667	779	678	724
797	726	883	849	767	843
240	140	151	138	241	150
320	389	400	276	342	337
521	266	531	390	394	548
623	491	577	549	656	638
495	553	690	659	753	658
233	142	183	154	225	147
276	425	524	299	421	442
574	358	644	423	462	585
653	436	641	664	760	592
788	743	745	860	731	802

V Measurements

108	60	152	196	144	147
160	168	224	176	220	172
174	175	300	255	226	205
223	251	363	476	352	331
404	365	384	470	462	497
102	148	206	186	160	158
102	196	276	148	204	192
193	204	247	372	191	224
311	302	370	420	352	329
373	421	479	393	462	479
84	86	208	164	161	119
100	156	195	158	192	144
148	192	309	320	173	189
305	243	364	315	301	325
296	339	438	671	493	379
118	128	252	221	180	195
168	221	241	250	296	204
219	218	358	250	201	207
422	434	420	400	413	301
374	400	897	401	553	390
125	112	260	137	159	166
70	221	202	132	244	158
231	196	314	253	178	212
385	382	445	378	396	362
466	445	410	263	478	450
103	72	217	135	138	161
83	181	140	140	209	158
148	148	276	247	189	182
300	261	339	351	306	308
384	353	310	277	457	479
133	84	155	127	117	142
113	174	203	166	211	110
158	147	285	268	183	182
291	262	388	304	252	298
420	401	471	310	517	397
120	115	219	161	156	138
131	186	202	128	219	144
163	211	274	226	214	155
302	289	367	303	286	328
443	414	292	338	375	458
114	121	169	169	142	168
148	209	184	178	221	177
186	247	292	231	155	160
306	305	336	335	374	285
347	379	362	447	462	392
110	83	204	162	143	149
140	156	203	163	187	161
140	170	259	241	171	164
304	291	383	342	343	269
377	346	373	287	536	342
78	138	184	79	71	221
283	222	248	278	401	290

359	254	374	406	474	441
388	336	419	566	327	478
554	732	793	545	762	546
98	81	188	60	96	232
274	256	370	212	413	360
474	218	259	348	425	419
451	334	480	630	362	476
618	669	480	402	623	658
123	90	180	74	103	81
224	235	239	235	320	162
332	230	358	360	283	390
405	261	454	464	275	346
617	518	434	356	430	766
80	82	152	86	105	212
174	253	210	309	396	412
323	238	313	479	324	387
385	373	552	650	447	752
480	637	597	515	641	655
73	71	183	54	101	175
131	255	268	324	343	226
292	231	325	356	374	357
290	298	411	539	347	458
389	502	523	524	423	502
209	149	213	140	138	295
266	296	464	296	223	318
442	372	428	395	372	507
790	341	532	627	592	488
694	689	582	652	566	788
143	71	158	45	111	190
233	226	218	230	328	244
256	211	369	371	380	363
279	292	413	443	337	401
526	640	456	466	421	532
87	67	178	58	105	134
193	192	187	291	351	291
324	236	281	367	405	446
379	383	441	714	376	518
516	531	522	459	486	611
96	57	143	40	53	74
140	193	217	227	269	200
250	188	296	264	361	391
256	247	326	466	332	435
368	384	378	366	617	436
72	55	172	59	118	93
144	285	216	271	308	283
260	211	296	313	413	396
328	272	419	547	451	432
536	608	472	488	476	466

C1 Measurements

64	192	39	104	148	60
176	208	292	224	180	256
288	269	204	254	318	283
189	441	230	268	420	269
244	247	184	348	126	267
82	111	37	80	136	87
183	140	326	284	180	290
348	230	277	324	349	248
97	410	180	228	381	298
267	193	260	355	87	244
68	138	24	84	172	81
104	164	280	223	172	243
29[illegible]	238	177	215	272	241
[illegible]	427	108	209	410	216
18[illegible]	202	350	679	120	216
77	33	45	112	179	105
137	172	321	487	217	232
411	253	174	268	368	304
164	514	239	228	520	298
269	261	616	370	117	302
57	180	48	181	221	88
237	163	326	296	188	316
289	297	228	350	396	343
209	383	108	322	443	318
230	208	310	500	98	263
73	149	28	144	167	61
168	150	279	220	182	214
326	230	131	274	292	295
97	479	135	256	366	276
175	182	246	409	94	193
38	164	42	152	177	78
164	149	285	223	172	221
271	290	176	366	318	280
86	509	185	252	417	269
217	185	320	390	76	172
80	137	31	132	140	61
117	148	335	246	179	208
230	223	186	256	262	305
58	364	167	300	420	228
218	157	196	313	93	234
72	106	35	112	190	77
135	151	290	236	163	230
326	222	194	262	275	300
106	388	178	330	276	338
319	213	271	281	110	240
62	135	28	118	130	7[illegible]
134	182	289	226	169	227
332	234	211	269	414	292
96	466	136	224	333	245
198	254	224	412	65	224
220	114	7	100	173	46
196	278	276	79	124	89

368	183	387	112	38	179
377	280	290	162	369	212
416	191	583	223	398	349
201	83	21	103	158	13
135	239	183	96	88	108
300	119	452	140	64	254
590	270	241	78	415	256
346	138	413	298	295	313
103	82	10	105	125	93
242	225	196	31	31	103
332	192	494	66	83	147
323	216	203	82	387	193
119	120	235	247	319	449
200	116	8	114	146	8
160	179	263	65	47	312
276	95	294	141	48	196
355	247	235	146	349	417
340	170	344	300	307	258
186	80	11	116	188	12
192	167	175	64	160	134
412	146	366	129	117	188
473	254	246	139	436	202
234	163	343	292	259	390
153	92	12	94	178	9
348	263	253	69	207	80
175	188	257	113	38	275
341	223	229	115	314	197
369	173	341	256	286	352
105	66	10	96	116	7
151	200	248	65	127	138
332	114	341	141	33	200
351	160	226	165	361	175
177	114	312	275	224	356
147	84	10	92	170	11
205	136	223	55	54	185
316	85	310	75	105	276
339	236	226	65	302	206
281	195	361	390	281	232
144	83	8	98	188	76
180	196	183	49	73	137
271	78	235	126	33	157
367	244	251	83	324	203
127	169	312	293	374	222
161	87	11	95	107	54
132	140	308	28	113	159
314	147	348	110	49	189
325	164	222	117	309	160
252	135	273	372	255	336

C2 Measurements

64	192	104	104	148	60
176	208	292	224	180	256
288	269	204	254	318	283
189	441	230	268	544	269
244	247	184	348	458	267
82	111	37	80	136	87
183	140	326	284	180	290
348	230	277	324	349	248
97	410	180	228	784	298
267	193	260	355	474	244
68	138	24	84	172	81
104	164	280	223	172	243
292	238	177	215	272	241
90	427	108	209	464	216
184	202	350	679	120	216
77	193	45	112	179	105
137	172	321	487	400	232
411	253	174	513	683	304
333	680	435	228	520	298
269	261	1143	370	117	302
57	180	48	181	221	88
237	163	326	296	188	316
289	297	228	350	396	343
413	383	108	322	443	318
230	208	310	500	98	263
73	149	28	144	167	61
168	150	279	220	182	214
326	230	131	274	292	295
97	479	135	256	820	276
175	182	246	409	94	193
38	164	42	152	177	78
164	149	285	223	172	221
271	290	176	822	572	280
86	509	185	252	417	269
217	185	320	390	241	172
80	137	31	132	140	61
117	148	335	246	179	208
230	223	186	256	262	305
58	364	167	300	420	228
218	157	196	313	354	234
72	106	35	112	190	77
135	151	290	236	163	230
326	222	194	262	275	300
106	388	178	330	276	338
319	213	271	281	174	240
62	135	28	118	130	73
134	182	289	226	169	227
332	234	211	269	414	292
96	466	136	224	333	245
198	254	224	412	65	224
220	114	7	100	173	211
196	278	276	79	124	546

368	183	387	112	38	276
377	280	290	420	568	890
416	927	968	223	774	838
201	83	21	103	158	13
135	239	183	96	88	108
300	119	452	140	64	966
590	270	241	78	415	256
346	138	413	298	436	313
103	82	10	105	125	93
242	225	196	31	31	103
332	192	958	66	435	147
791	216	203	82	713	660
119	409	235	247	319	1128
200	116	8	114	146	8
160	179	263	65	47	312
276	95	294	141	161	196
355	247	235	146	349	949
340	170	344	565	307	258
186	80	11	116	188	12
192	167	175	443	160	134
412	146	366	129	117	566
473	254	246	139	436	202
234	163	343	292	259	390
347	216	12	94	178	9
348	263	1569	69	972	629
175	188	355	113	212	775
1173	223	229	115	314	762
481	330	341	869	286	492
105	66	10	96	116	7
151	200	248	65	127	138
332	114	341	141	33	200
351	160	226	165	361	175
177	114	312	275	224	356
147	84	10	92	170	11
205	136	223	55	54	185
316	85	310	75	105	645
339	236	226	65	302	206
281	195	361	569	281	232
144	83	8	98	188	76
180	196	183	49	73	137
271	78	235	126	33	157
367	244	251	83	324	514
127	169	312	633	374	222
161	87	11	95	107	54
132	223	308	28	113	159
314	147	348	110	49	734
325	164	222	117	309	325
252	135	273	560	255	336

StV Measurements

108	60	152	196	144	147
92	128	120	116	180	112
70	91	124	161	64	92
33	95	145	152	124	100
88	172	96	46	83	64
102	148	206	186	160	158
64	161	140	128	140	111
82	58	134	236	64	116
56	106	128	128	120	88
91	140	81	65	85	72
84	86	208	164	161	119
60	124	117	94	140	82
68	64	146	217	52	78
56	92	96	111	124	88
65	56	136	70	56	72
118	128	252	221	180	195
111	153	154	145	193	104
94	79	134	134	64	100
93	154	151	200	136	96
92	112	109	64	72	68
125	112	260	137	159	166
52	132	134	100	196	102
91	73	164	133	62	117
67	102	122	111	137	110
92	186	56	60	93	111
103	72	217	135	138	161
52	144	84	93	161	80
78	34	110	104	55	82
71	98	108	102	107	83
100	104	58	50	94	127
133	84	155	127	117	142
72	130	128	111	151	74
53	57	111	97	51	90
81	104	120	108	79	75
65	114	81	38	161	90
120	115	219	161	156	138
73	126	154	104	151	92
88	72	124	107	62	64
61	95	121	98	117	99
91	104	82	78	58	112
114	121	169	169	142	168
92	135	113	96	150	96
83	98	112	142	51	76
64	88	111	92	106	92
73	94	64	63	77	79
110	83	204	162	143	149
67	113	133	97	132	91
63	45	99	137	52	70
60	109	126	149	122	80
77	98	72	32	92	61
78	138	184	79	71	221
167	149	173	100	216	209

128	94	136	146	197	199
169	147	160	142	65	175
159	165	119	153	164	131
98	81	188	60	96	232
133	169	197	61	200	234
163	70	38	126	166	170
182	104	192	160	143	177
194	174	96	123	229	117
123	90	180	74	103	81
139	126	171	55	167	90
121	110	121	109	52	140
159	85	181	97	75	81
197	171	77	97	109	101
80	82	152	86	105	212
118	162	130	110	173	123
113	117	68	202	51	197
133	132	181	197	155	255
139	165	142	145	143	132
73	71	183	54	101	175
61	168	137	147	147	123
104	113	159	122	145	144
114	106	130	142	127	181
129	136	102	158	137	118
209	149	213	140	138	295
145	194	151	105	223	196
205	236	172	160	110	224
499	97	187	178	214	160
228	175	122	209	185	150
143	71	158	45	111	190
150	135	136	57	144	112
73	95	156	106	146	152
77	105	115	110	124	151
135	131	90	125	75	135
87	67	178	58	105	134
112	139	128	107	180	161
84	114	114	129	157	200
153	140	154	244	117	263
173	108	84	219	162	107
96	57	143	40	53	74
90	135	134	67	125	105
107	79	106	97	115	156
87	80	117	139	95	228
120	112	75	88	185	117
72	55	172	59	118	93
88	181	166	109	125	152
87	112	119	86	196	153
156	88	124	145	185	130
143	196	92	178	100	85

1UstV Measurements

68	40	104	60	40	~~60~~
44	16	72	58	44	72
56	52	56	104	124	52
56	69	68	100	84	94
38	35	136	20	64	81
64	104	48	92	36	52
63	112	110	104	136	72
32	80	62	88	100	90
40	32	78	64	52	62
40	72	75	48	26	64
52	60	76	96	74	61
12	56	27	68	104	73
57	68	87	105	103	100
43	60	78	69	69	61
123	148	108	40	153	58
36	52	113	84	89	94
18	89	68	32	48	56
67	81	68	80	29	39
87	164	138	110	131	84
48	46	48	76	90	89
31	37	56	47	48	78
30	53	49	49	40	60
69	77	73	125	77	80
24	39	73	65	73	72
41	44	75	55	60	36
41	43	47	82	78	40
25	63	84	62	94	64
56	44	87	64	61	66
58	60	48	24	68	52
27	71	28	63	56	56
63	91	89	61	81	60
64	78	42	64	60	76
56	74	71	82	71	81
41	84	69	56	30	52
75	83	79	85	87	57
40	66	43	63	52	61
73	43	70	66	55	72
43	79	60	56	30	62
79	85	89	43	88	33
36	38	72	71	68	62
116	73	75	178	185	81
148	60	152	121	122	124
42	44	72	159	79	154
131	176	158	77	83	70
141	87	173	151	213	126
160	41	132	117	146	97
70	102	136	196	62	113
137	137	117	30	92	135
85	109	68	180	153	72
135	48	125	115	125	121
65	85	150	174	91	116
132	111	80	59	70	42

56	91	80	199	223	88
124	59	129	114	123	91
71	104	186	225	77	119
92	147	118	76	81	158
70	87	131	177	196	103
118	32	80	89	127	102
67	94	141	155	69	124
108	106	130	75	79	90
121	102	117	191	131	122
149	61	148	76	145	93
80	94	139	216	78	180
155	152	130	150	67	146
83	91	82	173	184	132
47	64	105	81	129	92
49	69	144	101	63	88
102	117	159	64	86	119
81	53	59	184	171	130
144	60	80	111	118	78
58	108	90	185	68	98
147	152	121	55	66	113
50	58	83	160	144	95
87	55	120	58	104	101
42	82	79	130	59	84
64	102	97	63	72	73
56	104	50	162	183	131
93	15	96	105	120	99
50	85	159	195	62	128
118	110	95	66	72	82