Quantitative Characterizations of Speech Rhythm: Syllable-Timing in Singapore English*

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KEY WORDS

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ABSTRACT

British English and Singapore English are said to differ in rhythmic patterning. British English is commonly described as stress-timed, but Singapore English is claimed to be syllable-timed. In the present paper, we explore the acoustic nature of the suggested cross-varietal difference. In directly comparable samples from British English and Singapore English, two types of acoustic measurements were taken; we calculated a variability index reflecting changes in vowel length over utterances, and measurements reflecting vowel quality. Our findings provide acoustic data which support the hypothesized cross-varietal difference in rhythmic patterning; we show (1) that successive vowel durations are more nearly equal in Singapore English than in British English, and (2) that reduced vowels pattern more peripherally in the F1/F2 formant space in Singapore English than in British English. We complete the paper with a comparison of our vowel variability index with a set of acoustic measures for rhythm proposed by Ramus, Nespor, and Mehler (1999), which focus on variability in vocalic and intervocalic intervals. We conclude that our variability index is more successful in capturing rhythmic differences than Ramus et al. (1999)'s measures, and that an application of our index to Ramus et al.'s intervocalic measure may provide a further diagnostic of rhythmic class.

INTRODUCTION

In the present paper, we explore the acoustic correlates of rhythm in two varieties of English: British English, which is said to be stress-timed, and Singapore English, which is said to be syllable-timed. At present, the suggested cross-linguistic difference rests on a relatively large number of studies examining the acoustic and perceptual correlates of rhythm in standard varieties of British and American English, and a relatively small number of impressionistic comments in the literature about the rhythmic characteristics of Singapore English (e.g., references to a "staccato rhythm," or "machine-gun" effect on the listener; see Brown,

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1988; Platt & Weber, 1980; Tay, 1982; Tongue, 1974). The acoustic basis of rhythm in Singapore English has largely remained unexplored, and hitherto, directly comparable cross-varietal data have not been available. In the present study, we offer evidence from two types of acoustic measurements taken from such data, vowel duration, and vowel quality. Additionally, we present a new method for the processing of duration measurements taken in the investigation of rhythm: the "Pairwise Variability Index" or PVI. This index captures the degree of durational variability in a set of acoustic data, measured sequentially, and it allows us to express numerically a tendency towards stress- or syllable-timing in one language or variety relative to another. We conclude the paper with a comparison of the PVI with several measures of rhythmicity suggested by Ramus et al. (1999).

BACKGROUND

Rhythmic classifications such as stress-timing and syllable-timing are based on the assumption that we can posit a dichotomy between languages which exhibit more nearly equal intervals between stresses or rhythmic feet on the one hand, and languages which display near isochrony between successive syllables on the other (Abercrombie, 1967; Pike, 1945). Although this classification has long served as a useful shorthand, and reflects relatively well the endpoints of a continuum between two distinct rhythmic options, the acoustic basis of the dichotomy has remained somewhat shaky and some scholars have concluded that isochrony is primarily a perceptual phenomenon (Couper-Kuhlen, 1990, 1993; Lehiste, 1977). A number of monolingual studies have shown that isochronous feet cannot be related to constant interstress intervals in stress-timed languages (Bolinger, 1965; Faure, Hirst, & Chafcouloff, 1980; Lehiste, 1990; Nakatani, O'Connor, & Aston, 1981; Shen & Peterson, 1962; Strangert, 1985), and successive syllable durations tend to be far from equal in syllable-timed languages (Delattre, 1966; Local, Wells, & Sebba, 1985; Manrique & Signorini, 1983; Pointon, 1980). Attempts to resolve the issue by contrasting stress- and syllable-timed languages have fared little better; interstress intervals in stress-timed languages do not appear to be more regularly spaced than in syllable-timed languages (Dauer, 1983; Roach, 1982,). More recently, Couper-Kuhlen (1993) investigated the question of acoustic and perceptual isochrony in English, and Auer, Couper-Kuhlen, and Muller (1999) and Ramus et. al. (1999) studied the acoustic characteristics of rhythmic classes across languages.

Acoustic data reflecting cross-*varietal* differences in rhythmic patterning, on the other hand, are virtually nonexistent, and most textbooks classify English as stress-timed, ignoring for the sake of brevity the varieties of English such as Singapore English which are rhythmically more similar to standard French, a syllable-timed language (Brown, 1988; Platt & Weber, 1980; Tay, 1982; Tongue, 1974). Thus, at present, we know very little about the acoustic correlates of syllable-timing in Singapore English, and so far, no satisfactory account of the rhythmic differences between Singapore English and so-called standard varieties of English such as General Southern British English has been offered. A pioneering study was carried out by Yeow (1987) who compared foot length in Singapore English and British English. This approach failed to offer a satisfactory account of syllable-timing, probably because stressed syllables are often impossible to identify in Singapore English, and as a result, utterances are extremely difficult to segment into feet (Low, 1998). Brown (1988, 1991) and Taylor (1981) suggested an alternative to measuring foot or syllable duration. They claimed that vowel reduction patterns in Singapore English and British English differ; in British English, stressed and unstressed syllables differ in vowel length, but in Singapore English, they do not. This as yet unsubstantiated observation suggests that the acoustic correlates of syllable-timing in Singapore English may involve vowel duration and vowel quality rather than syllable-duration.

The contribution of vowel reduction to the impression of stress- and syllable-timing was investigated more generally in studies by Bertinetto (1977), Brakel (1985), and Wenk and Wioland (1982). The data presented in these studies confirm that the basis for attributing stress- or syllable-timing may involve vowels rather than syllables. In British English, syllables in a foot are compressed to approach foot isochrony, and vowel reduction is exploited to achieve this compression. Syllable-timed languages like French do not need to achieve foot isochrony and do not exploit vowel reduction for rhythmic purposes. However, even if a language is reportedly syllable-timed, speakers may find it useful to achieve foot isochrony even if the isochrony is not achieved via the compression or reduction of unstressed syllables, as evidence from Italian shows (Auer et. al., 1999). As Singapore English is said to be syllable-timed, it is possible that this variety of English does not use vowel reduction in unstressed syllables to achieve foot isochrony either.

Finally, as far as English is concerned, there are at least two further reasons why an investigation of vowels may shed more light on the acoustic correlates of rhythmic distinctions than an investigation of syllable durations or interstress intervals. Firstly, syllable boundaries are notoriously difficult to determine in English, and one cannot necessarily assume that consistent syllable duration measurements can be taken (e.g., compare the number of syllables in *higher* and *hire*, and where is the syllable boundary in *attic*?). Vowel durations, on the other hand, can be measured with a higher degree of reliability. Secondly, vowel quality is the acoustic property responsible for prominence distinctions at the lowest level of the prosodic prominence hierarchy in English (Beckman & Edwards, 1994; Bolinger, 1964, 1986; Liberman & Prince, 1977)[1], and therefore, a cross-varietal difference in vowel production is more likely to provide us with an account of syllable-timing in Singapore English than an investigation of syllable duration. In the present study, we put this hypothesis to the test.

EXPERIMENTAL INVESTIGATION

Method

Materials

Ten Singapore English (SE) and ten British English (BE) speakers took part in a production task. The speakers were asked to read a list of ten sentences divided into two sets (the materials are given in the *Appendix*). The first set contained a mixture of full and potentially

[1] See Fear, Cutler, and Butterfield (1995) for an experimental investigation of the strong-weak syllable distinction in English. The authors show that in production, unstressed unreduced vowels differ significantly both from stressed, full vowels and from reduced vowels. Nevertheless, listeners make a binary categorical distinction between strong and weak syllables on the basis of vowel quality, that is, a syllable with a full vowel is classed as strong and one with a reduced vowel as weak.

reduced vowels (the "Reduced Vowel Set"), and the second set contained only full vowels (the "Full Vowel Set"). An example from each set and a transcription reflecting General Southern British English is given in (1) below.

(1)	Full Vowel Set:	*John came back through France last Sunday.*
		/dʒ n keɪm bæk θruː frɑːns læst sʌndeɪ/
	Reduced Vowel Set:	*John was sick of Fred and Sandy.*
		/dʒ n wəz sɪk əv fred ən sændɪ/

The Full Vowel Set and the Reduced Vowel Set were designed to allow for a number of cross-varietal comparisons. We tested: (a) whether successive vowel durations in our Singapore English sample were more nearly equal than successive vowel durations in our British English sample (as one would expect in a "syllable-timed" language); (b) whether syllable-timing in the Singapore English sample involved an absence of vowel reduction; or (c) whether the rhythmic differences between the samples involved a combination of durational differences and difference in vowel reduction.

The test sentences were presented to the speakers in pseudorandomized order. No context was given, and no fillers were used, as the sentences were quite different.

Recording procedure

The Singapore English materials were read in the sound-treated language laboratories at the National Institute of Education (NIE) in Singapore, and recorded on a Sony TC-172 cassette recorder with an attached microphone, placed at a distance of about 25 centimeters from the subject's mouth. Subjects were given time to read the sentences before the recordings began, and when hesitations or errors occurred during the recordings, subjects were asked to repeat the tokens at the end of the session.

The BE subjects were recorded in a sound-treated room at the Phonetics Laboratory of the University of Cambridge using a Sony DTC 55ES digital audio-tape deck and a Sennheiser MKH 40 P48 condenser microphone with cardioid response fed through a Symetrix SX202 preamplifier. The distance of the microphone from the subjects' mouths was varied according to the amplitude of their voices displayed by the peak level signal bar so that the recordings would not be clipped. Again, tokens with errors or hesitations were re-recorded at the end of each session.

Subjects

The linguistic situation in Singapore is by no means homogeneous. The multilingual and multiethnic composition of the population (78% Chinese, 14% Malay, 7% Indian, and 1% "Others"), the status of English as a second language, the prevalence of bi- and tri-lingualism and interference from the mother tongue are variables which exercise considerable influence on a speaker's linguistic performance. Pakir (1991) has described Singapore English as varying on a cline of proficiency and formality; the level of proficiency in English amongst Singaporeans varies with their educational qualifications and the formality of their speech situation. For the purposes of the present study, we attempted to hold the ethnic and educational variables constant. Since the Chinese form the majority of the population, five male and five female subjects were selected from the Chinese group. All speakers were undergraduates from the National University of Singapore, aged between 20 to 22 years.

In Britain, English varies primarily along the sociolectal and dialectal or regional dimensions. Although Received Pronunciation (RP) is often identified as the accepted and prestigious social standard of pronunciation, it is extremely difficult to identify "real" RP speakers. For our study, we chose 10 undergraduates from the University of Cambridge (again, five were male and five were female), also aged between 20 to 22 years, who had been brought up and educated in the south of England.

EXPERIMENT 1: VOWEL DURATION

Method

The recorded corpus of data contained 200 utterances (100 SE, 100 BE) which were digitized with a sampling rate of 16 Hz using xwaves(TM), a commercially available signal processing software package available from Entropic.

Although the presence of a vowel can be determined relatively easily when inspecting a wide-band spectrogram, the boundaries of vowels are not always unambiguously definable. Where possible, vowels were identified using generally accepted criteria such as the onset of the second formant (see Peterson & Lehiste, 1960 for a full set of criteria).

Cross-varietal differences in the number of vowel segments and the number of syllables

Two problems were encountered during the vowel duration measurements, the first of which involved cross-varietal differences in the presence or absence of vocalic segments. In the BE samples, in the productions of some speakers, we found no evidence of a (potential) vocalic segment following a voiceless plosive. The second syllable of the word *suspicious*, for instance, can be produced as an aspirated voiceless plosive [pʰ]; and in that case, there is no vowel duration one can measure. In the SE samples, on the other hand, the duration of the vowel following the plosive could always be measured. In such cases, in order to maintain direct comparability, we considered the plosive, the period of silence before the vowel and the following vowel (if present) as part of the vowel in both varieties.

The second problem involved cross-varietal differences in the number of syllables in the realizations of a small number of words. For example, the citation form of the word *totally* in BE is transcribed as /təʊ-tə-lɪ/, consisting of three syllables. However, many BE speakers produced the word as [təʊ-tʰl̥ɪ], with two syllables whereas the SE speakers always produced three syllables. To counteract this problem, *totally* was assumed to have three syllables in SE and in BE. In SE, the complete duration of the second syllable was taken (i.e., the stop was included), and in BE, the aspirated [tʰ] was taken to reflect a "devoiced" vowel, and the duration of the plosive was measured.

Hypothesis

We hypothesized that vowel durations would be more nearly equal in duration in SE, which is said to be syllable-timed, than in BE, which is stress-timed.

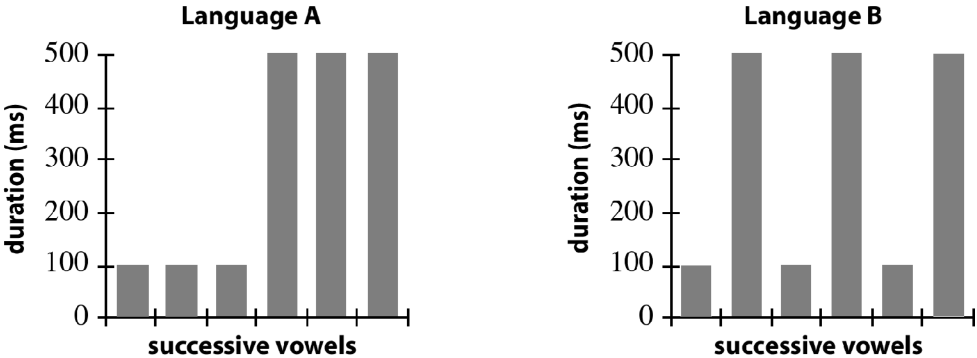

Figure 1

Successive vowel durations of two hypothetical languages A and B

Analysis

In order to test the hypothesis that vowels are more nearly equal in duration in SE than in BE, a measure was needed to summarize the patterning of durations in the two samples. For instance, one might calculate and compare the standard deviation from the mean in the two varieties of English. However, if one finds that SE and BE exhibit similar standard deviations from the mean, this need not necessarily indicate that the patterning of successive vowel durations in SE and BE are indeed similar. Consider the following hypothetical example representing the differences in successive vowel durations between two languages A and B:

Language A and B exhibit different overall patterns in their successive vowel durations. Nevertheless, the standard deviation from the mean is 200 in both (the mean is 300 ms in both languages, and the standard deviation from the mean is 200). However, Language A appears to behave more like a syllable-timed language; successive vowel durations are equal, even though there are two different groups of nearly equal durations, and the difference could be the result of a faster speaking rate in the first half of the utterance. Language B, on the other hand, exhibits a steady alternation between longer and shorter vowel durations, rather like what one would expect for an idealized stress-timed language. Yet, although the patterning of successive vowel durations in Language B clearly differs from Language A, both languages emerge with the same standard deviation value.

A measure which more securely reflects the alternations of longer and shorter vowels would be the mean absolute difference between successive pairs of vowels in an utterance, combined with a normalization procedure for speaking rate. The following formula provides such a measure, and we will refer to this measure as the "Pairwise Variability Index" or PVI.[2]

[2] A note on the history of the Pairwise Variability Index: the use of a rhythm index was originally suggested by Francis Nolan, and a first v on of the index was employed in an investigation of rhythmic differences between Singapore English and British English in Low's (1994) M. Phil thesis. The index was then adopted in modified form by Deterding (1994a) who added a normalization component and applied the index in an investigation of spontaneous speech. The index was further developed in Low and Grabe (1995), and Low (1998). In the present paper, we use the Low (1998) version of the index.

The formula in (2) shows that the PVI is compiled by calculating the difference in duration between successive syllables, taking the absolute value of the difference and dividing it by the mean duration of the pair. In doing this, the values obtained are normalized across speakers independent of their individual speaking rates. The differences are then summed and divided by the number of differences. The output is multiplied by 100, because the normalization produces fractional values.

Predictions

Firstly, we predicted that PVI values for SE would be significantly smaller than for BE, reflecting less durational variability between successive vowels, and a tendency towards syllable-timing. In BE, we expected to find more durational variability between successive vowels, reflecting a tendency toward stress-timing.

Secondly, we predicted that the Reduced Vowel Sets would differ in the two varieties (recall that we hypothesized that SE either has no reduced vowels or that reduced vowels in SE differ from reduced vowels in BE), but that the Full Vowel Sets would not differ across varieties. Table 1 summarizes the predictions made for PVI values across varieties.

TABLE 1

Summary of predictions made for duration across varieties

	SE	***BE***
Total PVI	different	
Full Vowel Set	similar	
Reduced Vowel Set	different	

Thirdly, we expected a durational distinction between full and reduced vowels in BE, but not in SE. In the BE data we expected to find significantly higher PVI values (i.e., more variability) in the Reduced Vowel Set (which contained full and reduced vowels) than in the Full Vowel Set because reduced vowels tend to be noticeably shorter in BE than full vowels. In the SE data we expected that durational vowel reduction would be absent, and PVI values in the Reduced and the Full Vowel Set would be similar. Table 2 (overleaf) illustrates the predictions made for PVI values within varieties.

Results

The PVI results for duration supported our predictions and are illustrated in Figure 2.

The PVI values were subjected to a repeated measures Analysis of Variance with the dependent variable “PVI duration values” and the independent variables Variety (SE, BE)

TABLE 2

Summary of predictions made for duration within varieties

SE		*BE*	
Full	Reduced	Full	Reduced
similar		different	

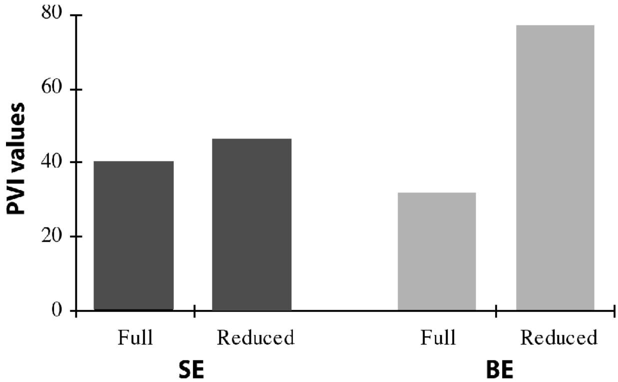

Figure 2

PVI duration results

and Set (full, reduced). Significant main effects of Variety, $F[1,4] = 17.5$, $p < .01$, and Set, $F[1,4] = 292.9$, $p < .001$, emerged, as well as a significant interaction between Variety and Set, $F[1,4] = 52.9$, $p < .001$; all values are Greenhouse-Geisser corrected)[3]. Planned comparisons showed that, as predicted, within SE, Full, and Reduced Vowel Sets did not differ, reflecting the absence of a durational distinction between full and reduced vowels, but within BE, the difference was very highly significant ($p < .001$). Secondly, the planned comparisons showed that the Reduced Vowels Sets in BE and SE differed significantly ($p < .001$), but the Full Vowel Sets did not.

Thus, our duration data show that SE exhibits less variability in successive vowel durations than BE. This finding supports our predictions, and is consistent with comments in the literature about syllable-timing in SE. Additionally, the data suggest that an absence of durational vowel reduction plays a significant role in the impression of syllable-timing in SE (recall that the Full Vowel Sets did not differ across the two varieties, but the Reduced Vowel Sets did). However, from the absence of durational vowel reduction in SE, we cannot conclude that SE does not have reduced vowels as such; it may be the case that vowel reduction in SE involves spectral patterning, but not duration. We address this question in the following section.

3 In statistical designs involving cross-linguistic data, the variables Speaker and Language (or Variety) are necessarily confounded. The confound can be dealt with by calculating the statistics using means taken across speakers, and this is why the ANOVA presented above was calculated using the means from the 10 speakers in each variety.

EXPERIMENT 2: SPECTRAL PATTERNS IN VOWELS

Introduction

The question of how exactly one should define a reduced vowel is surrounded by some degree of controversy. Before we give the definition of the term "reduced vowel" in the present study, we will briefly discuss the concept of vowel reduction. This will be discussed with respect to three issues:

(i) what are the acoustic correlates of a reduced vowel?

(ii) where and when do reduced vowels occur?

(iii) what are the problems surrounding their definition?

What are the acoustic correlates of a reduced vowel?

The term "reduction" suggests a deviation from an ideal target or a failure to reach that target. Koopmans van Beinum (1980) suggests that a reduced vowel may be defined as a deviation in the acoustic vowel space from an ideal position (or target) towards a midcentral point in the vowel quadrilateral. This movement towards a midcentral point in the vowel diagram is accompanied by differences in amplitude and duration (Lindblom, 1963), that is, a reduced vowel is characterized by lower amplitude values and shorter duration than its full counterpart. Shearme and Holmes (1962) have termed this midcentral point in the vowel quadrilateral the "neutral-vowel" position, since it is produced when the vowel tract configuration is neutral. "Neutral" refers to a configuration where both the active and passive articulators are lying directly opposite each other and the lips are in a slightly open position (Laver, 1994). This neutral vowel position is often associated with the articulatory position for schwa (/ə/), and schwa can often be identified from a wide-band spectrogram by its characteristic, roughly equal spacing of formants (Peterson & Barney, 1952). "Ideal" positions or targets, on the other hand, are those vowel positions that provide the greatest acoustic contrasts, and are often found at the periphery of a speaker's acoustic space.

Where and when do reduced vowels occur?

The application of vowel reduction appears to be correlated with speaking style and stress. Tiffany (1959), for instance, carried out a comparative study of isolated vowels, stressed vowels, and unstressed vowels in read speech samples produced by trained and untrained American speakers, and found that the acoustic vowel diagram appeared to become smaller from isolated vowels to stressed vowels to unstressed vowels. In other words, vowel realizations appeared to move towards the centre of the vowel quadrilateral when vowels in citation forms were compared to vowels in connected speech (i.e., in read sentences) and when prominence was reduced (i.e., in stressed vs. unstressed vowels). Similarly, Shearme and Holmes (1962) compared BE vowels in isolated monosyllables with vowels in read text and found a displacement towards a "neutral-vowel" position for vowels produced when subjects read a piece of prose. Kohler (1990) correlates the degree of vowel reduction encountered with the lowering of the stylistic level and with the degree of familiarity in a speech situation, and states that in unstressed positions, function words in English (e.g., auxiliary verbs, prepositions, and conjunctions) are reduced. He explains the concept of vowel reduction in unstressed syllables in terms of the principle of articulatory economy, and suggests that in unstressed words, the distances travelled by the articulators are reduced.[4] This results in schwa-like vowel productions which are, at the same time, shorter than the unreduced forms they are related to because of the shorter trajectories into and out of the more midcentral vowel targets and the general shortening of vowels in unstressed position. The principle of articulatory economy is said to follow from the stress-timing principle of languages like German. In stress-timed languages, since the number of syllables in a foot varies, there must be a way of compressing syllables in a foot in order to approach isochrony. Although isochrony cannot be complete, it is at least partially achieved by the compressibility of function words and unstressed syllables in general. This compressibility is generally realised by shorter durations and less movement away from the midcentral position in the speaker's vowel quadrilateral approximating that of a schwa. Finally, the degree of vowel reduction encountered is language-specific. Lindblom (1963), for instance, describes vowel reduction as a characteristic of languages with heavy stress like German and English. Delattre (1969) who studied the acoustic and articulatory factors of vowel reduction in four languages concluded that "the extent of vowel reduction due to unstressing in medial position is much greater in English than in the three other languages examined, namely, German, French and Spanish."

Problems surrounding the definition of reduced vowels

One of the problems surrounding the definition of reduced vowels involves the question of whether we can assume that the terms "reduced vowel" and "schwa" are synonymous. The term "reduced vowel" implies some kind of dependency between the realization of a reduced vowel and the characteristics of the full vowel which one would have encountered if vowel reduction had not applied. Schwa, on the other hand, could be an independent vowel in its own right, and have its own articulatory target. Evidence for the independence of schwa comes from work by Browman and Goldstein (1992) who demonstrate that schwas occurring in symmetrical vowel contexts (such as between two syllables containing /i/) exhibited a clear tongue body movement away from the position required by the flanking full vowels. Although Browman and Goldstein's study does not allow them to specify an independent target position for schwa, their study shows that the characteristics of schwa are not always determined by surrounding vowels and consonants, and therefore, schwa cannot be considered targetless. If schwa cannot be reliably associated with targetlessness, (which, according to Kohler, 1990, is a principle governing vowel reduction), then the terms reduced vowel and schwa cannot be synonymous. Other studies presenting evidence supporting the claim that the quality of schwa is strongly affected by the acoustic and articulatory properties of its neighboring vowels and flanking consonants (Alfonso & Baer, 1982; Fowler, 1981), and at present, the question of whether schwa is always a reduced vowel is still open. A related problem involves the expectation that all reduced vowels approach a schwa-like quality. While this is true for the majority of reduced vowels, there

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4 But note that the principle of articulatory economy breaks down when we consider the occurrence of so-called "intrusive" or "linking" /r/ in English (e.g., in *I saw him* /ɑɪ sɔːrɪm/).

is a small proportion which may be realized with a different quality. For example, the weak form of the past tense inflection in the word *wanted* does not have a schwa-like quality, but is realized in BE as a close-mid unrounded vowel in the general area of /ɪ/.

The term reduced vowel in the present study

In the present study, we have investigated the type of vowel reduction found in function words or modals such as *to* or *was* in BE. In BE, the vowels in *to* or *was* are usually reduced to schwa, the weak variant of the vowels /uː/ and /ɑː/. In the following sections, we compare the spectral patterns of schwa in BE with spectral patterns produced in the same positions by SE speakers. The vowels investigated will be referred to as "potentially reduced vowels" since it is likely (though not inevitable) that they will be reduced in BE, but not in SE.

Method

Measurements

We measured the location of the first and the second formant (F1 and F2) in all vowels in the Reduced Vowel Set (in other words, in full and in potentially reduced vowels). In BE, full vowels were taken to be associated with formant patterns located around the periphery of the speaker's acoustic vowel space, while reduced vowels were assumed to be characterized by formant patterns approaching the midcentral region of the F1/F2 space.

Formant frequencies were measured on wide-band spectrograms displayed by xwaves(TM). In monophthongs, formant values were measured at the midpoint of the vowel where the perturbations caused by surrounding consonants are minimized (Beckman, 1986). For diphthongs, which do not have a steady state, two readings were taken. The first set of measurements was taken roughly from what appeared to be the centre of the first portion of the diphthong, and the second set was taken at approximately the centre of the second portion.

Hypothesis

We hypothesized that vowel reduction in SE is weaker than in BE, or altogether absent, and that this lack of vowel reduction contributes towards the impression of syllable-timing in SE.

Analysis

A comparison of F1 and F2 formant values produced by SE and BE speakers requires a quantification measure. For the purposes of the present study, we calculated the degree of vowel centralization, a measure suggested by Koopmans van Beinum (1980). The vowel centralization measure determines the dispersion of F1/F2 values from the "centroid," which is the mean F1 and mean F2 value calculated from all F1/F2 values in a speaker's data.

In her explanation of how to calculate the dispersion from the centroid, Koopmans van Beinum states the following: "Since two values, characteristic of a certain notion, can be represented as a point in a plane, having these two values as coordinates, a vowel V_i can be represented by a vector defined by an ordered pair of values (v_1, v_2)" (1980, p. 58).

Therefore,

$$\vec{V_i} = (V_{1_i}, V_{2_i}).$$

$$\bar{\vec{V}} = \frac{1}{n} \sum_{i=1}^{n} \vec{V}_i = \vec{S}$$

The mean vector represents the centroid S of a system with n vowels. The distance of vowel to the centroid is defined as:

$$d_{V_i, S} = |\vec{V_i} - \vec{S})$$

The dispersion or what Koopmans-van Beinum calls "the total variance of a vowel system from the centroid" is the mean sum of squares of d:

$$D = \frac{1}{n} \sum_{i=1}^{n} |\vec{V_i} - \vec{S})^2$$

The values obtained are expressed as arbitrary units. In the present paper, the results were then divided by 100,000 in order to obtain manageable values.

Predictions

We predicted a cross-varietal difference in spectral patterns characterizing full and potentially reduced vowels. Specifically:

In BE, we expected a distinction between full and potentially reduced vowels. The potentially reduced vowels would form a central cluster in the speakers' F1-F2 formant space but, as shown in Figure 3, the full vowels would occur at the periphery. In other words, potentially reduced vowels would be associated with a smaller dispersion from the centroid than full vowels.

In SE, assuming that SE does not have vowel reduction, we did not expect a clear spectral distinction between full and potentially reduced vowels. F1/F2 values for both sets of vowels were predicted to pattern around the periphery of the speakers' F1-F2 formant space, as shown in Figure 4, and dispersion values for full and potentially reduced vowels were predicted to be similar.

Finally, we predicted that a cross-varietal comparison would confirm that potentially reduced vowels in SE and BE were realized differently. The SE versions of the vowels would be located at the periphery of our speakers' F1-F2 formant space while the BE vowels would form a central cluster. This is shown in Figure 5. Thus, we expected a larger dispersion value in potentially reduced vowels in SE than in BE.

Results

In BE, we expected a spectral distinction between full and potentially reduced vowels, and our measurements confirmed this prediction. The results are illustrated in Figures 6 and 7. For the sake of clarity, separate diagrams are given for male and female speakers; otherwise, the patterning of F1/F2 values is somewhat confounded by sex-specific differences in spectral patterning (Peterson & Barney, 1952). Figure 6 shows F2 plotted against F1 for male speakers, and Figure 7 illustrates the results for female speakers.

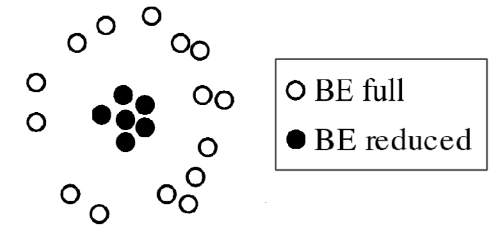

Figure 3

Prediction for F1/F2 values in full and potentially reduced vowels in BE

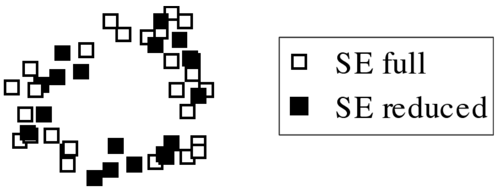

Figure 4

Prediction for F1/F2 values in full and potentially reduced vowels in SE

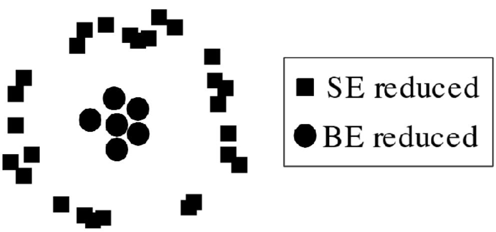

Figure 5

Prediction for F1/F2 values in potentially reduced vowels in SE and BE

Figures 6 and 7 show that BE speakers produced a spectral distinction between full and potentially reduced vowels. As predicted, potentially reduced vowels form a central cluster in the speakers' F1-F2 formant space while full vowels are located towards the periphery of the speakers' formant space.

Figures 8 and 9 illustrate the results for SE, where we did not expect a clear spectral distinction between full and potentially reduced vowels. This prediction was not confirmed by the data. Figures 8 and 9 show that SE speakers do make a distinction between full and potentially reduced vowels, even if the distinction is not quite as clear-cut as in BE.

In order to quantify our measurements, we calculated the dispersion of full and reduced vowels from the centroid using Koopmans van Beinum's formula. At this point, the data from male and female speakers were collapsed. Figure 10 illustrates the results.

The dispersion values were subjected to a repeated measures Analysis of Variance with the independent variables Variety (SE, BE) and Vowel type (Full, Reduced) and the dependent variable "dispersion from centroid." Significant main effects of Variety, $F_{[1,4]} = 14.4, p < .01$, and Vowel type, $F_{[1,4]} = 28.1$ $p < .01$, emerged, but the interaction was not significant. Thus, the dispersion of F1/F2 values from the centroid differed in the two varieties of English; in SE, the dispersion was significantly greater than in BE. Secondly, the results show that speakers made a clear distinction between full and reduced vowels in both varieties of English (recall that we predicted that full and reduced vowels would exhibit similar dispersions in

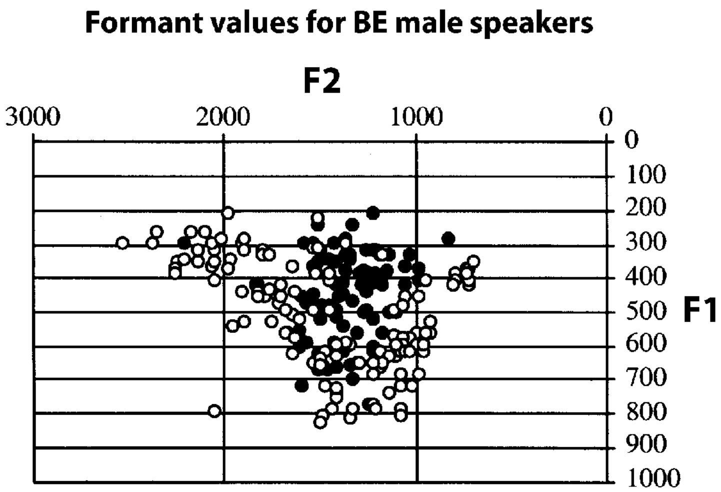

Figure 6

Full and potentially reduced vowels produced by BE male speakers

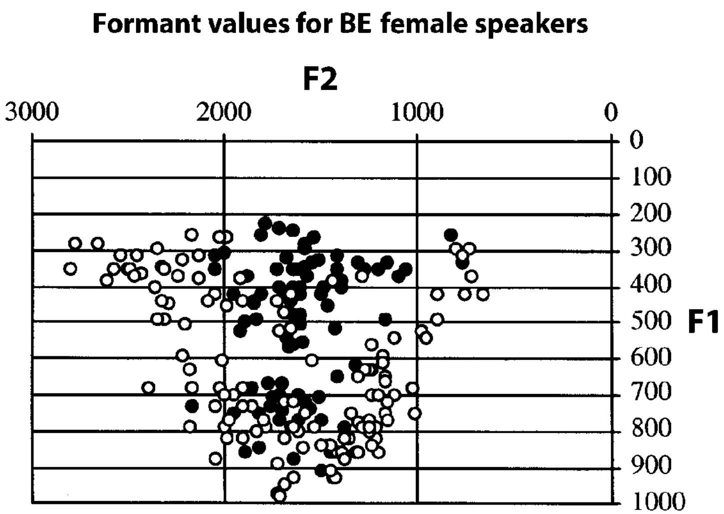

Figure 7

Full and potentially reduced vowels produced by BE female speakers

SE). Planned comparisons showed that the difference between full and potentially reduced vowels was very highly significant in BE ($p < .001$) and highly significant in SE ($p < .01$). Further calculations showed that in SE, the dispersion of full vowels was twice as large as that of potentially reduced vowels, whereas in BE, the dispersion of full vowels was 3.6 times as large. However, a t-test showed that this difference in magnitude was not significant.

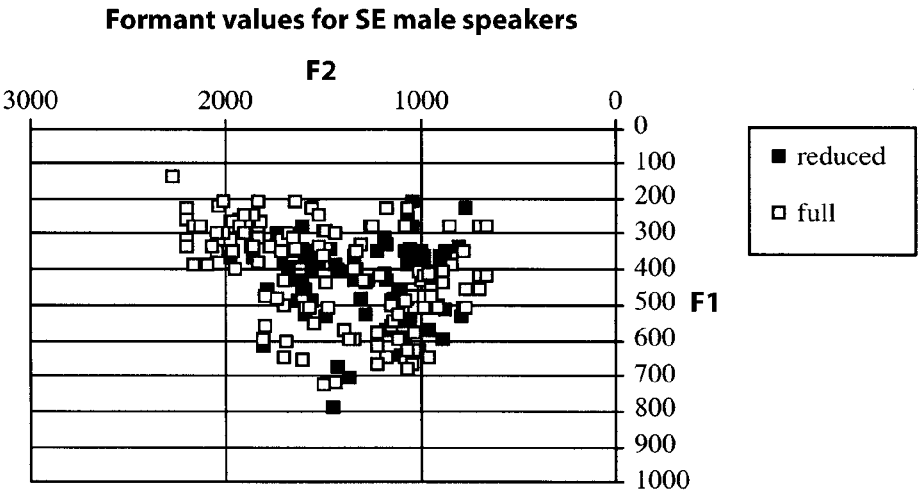

Figure 8

Full and potentially reduced vowels produced by SE male speakers

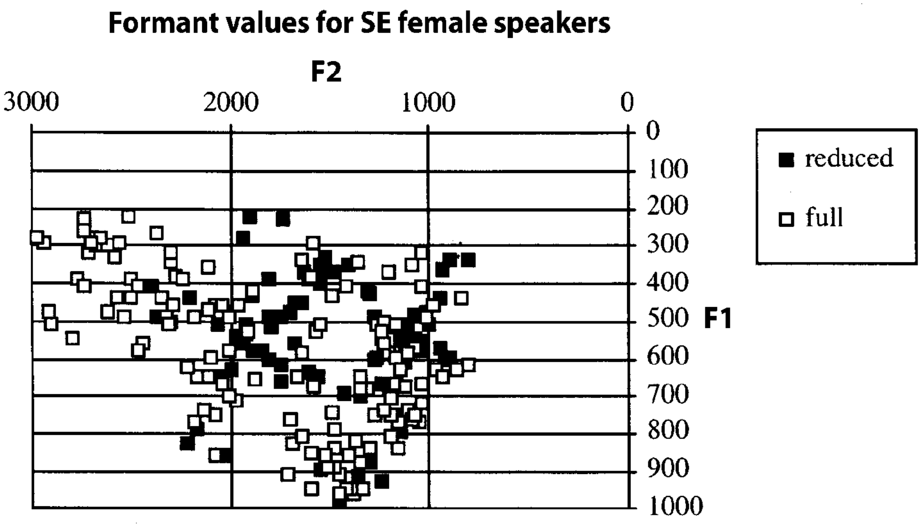

Figure 9

Full and potentially reduced vowels produced by SE female speakers

Our third and final prediction involved the realisation of potentially reduced vowels in SE and BE. We predicted that potentially reduced vowels would be located closer to the periphery of our speakers' F1-F2 formant space in SE than in BE. This comparison is illustrated in Figures 11 for male speakers, and Figure 12 for female speakers.

Figures 11 and 12 show that the F1/F2 values obtained from the BE samples are located

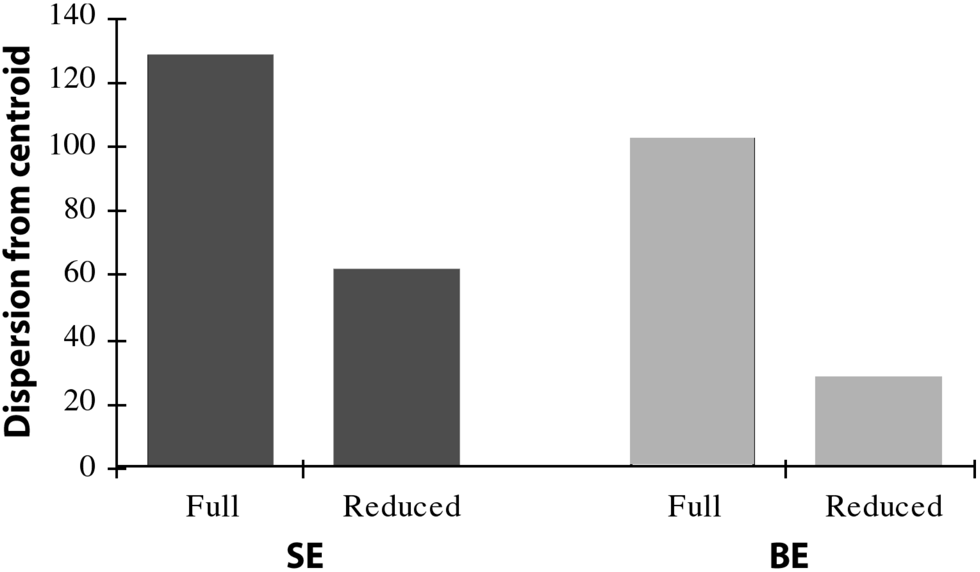

Figure 10

Dispersion from centroid for full and potentially reduced vowels in SE (left) and BE (right)

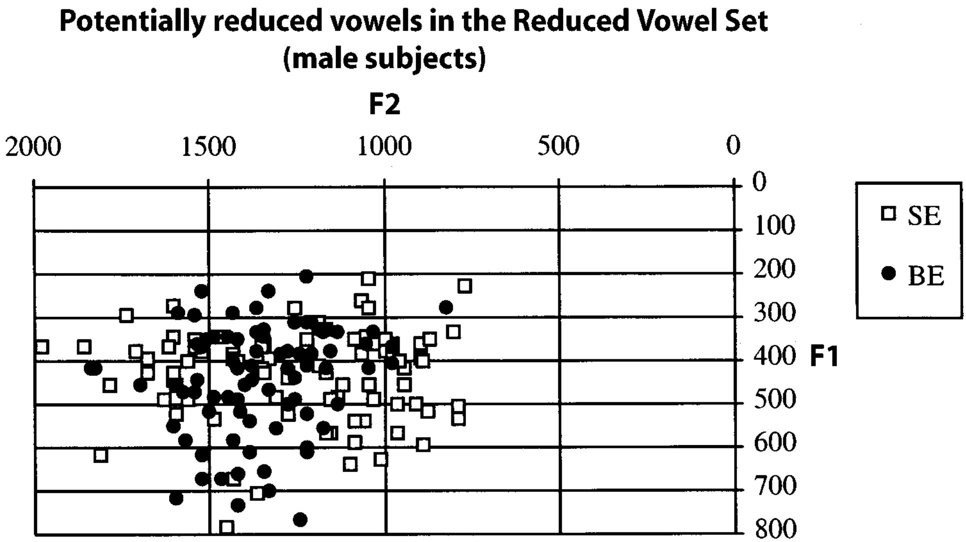

Figure 11

Potentially reduced vowels in the Reduced Vowel Set for male speakers

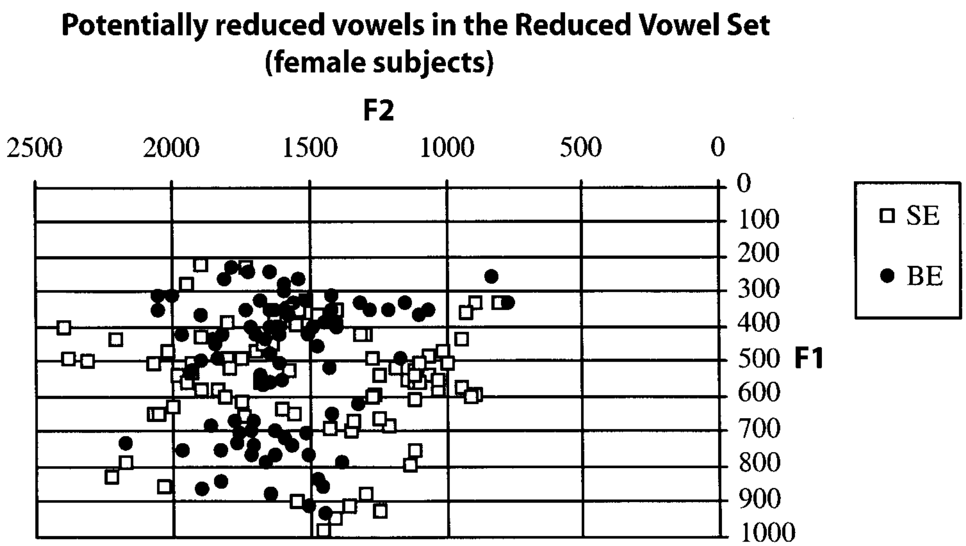

Figure 12

Potentially reduced vowels in the Reduced Vowel Set for female speakers

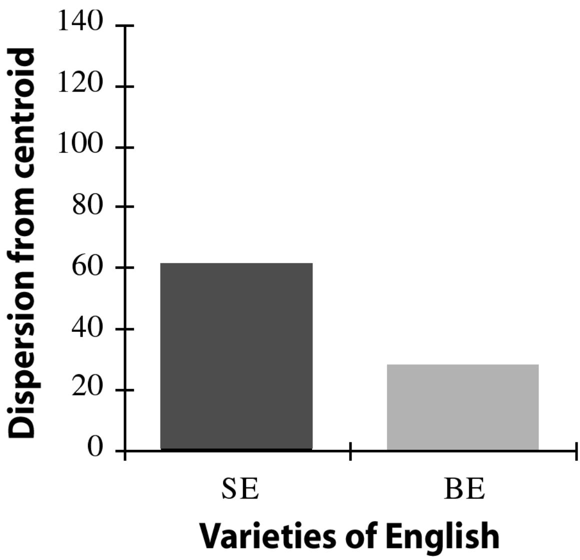

Figure 13

Distance from centroid in potentially reduced vowels in the two varieties

closer to the centre of the F1/F2 space than those obtained from the SE samples. This finding concurs with our prediction; in BE, potentially reduced vowels form a central cluster in the F1-F2 formant space, whereas in SE, they pattern more peripherally. The dispersion from the centroid in reduced vowels in the two varieties is illustrated in Figure 13.

The results in Figure 13 support our prediction. SE speakers produced potentially reduced vowels at a greater distance from the centroid than BE speakers, and planned comparisons showed that the difference was significant ($p < .05$).

The results from the experimental investigations reported thus far provide acoustic evidence for the impression of syllable-timing in SE since SE speakers had a lower PVI value between successive vowels than BE speakers. Additionally, results from the investigation on vowel quality differences showed that SE speakers exhibited a more peripheral spectral pattern for potentially reduced vowels than BE speakers.

A COMPARISON OF THE PAIRWISE VARIABILITY INDEX WITH OTHER RHYTHMIC MEASURES

In the remainder of this paper, we return to duration as an acoustic correlate of rhythm. We put our Pairwise Variability Index to the test, by comparing the measure with a set of acoustic correlates of rhythm classes proposed by Ramus et. al. (1999). Ramus and colleagues set out to provide acoustic evidence for the traditional stress-timing/syllable-timing dichotomy, and investigated three acoustic correlates of rhythm: %V: the proportion of vocalic intervals in the sentence (vocalic interval = section of speech between vowel onset and vowel offset), ΔV: the standard deviation of vocalic intervals, and ΔC: the standard deviation of consontantal intervals (consonantal interval = section between vowel offset and vowel onset). In what follows, we will refer to ΔC to as "ΔIV", the standard deviation of intervocalic intervals. On the basis of their findings, Ramus et al. argue that %V is the measure which offers the best acoustic correlate of rhythm classes. For instance, %V is smaller in English, which is said to be stress-timed, than in French, which is said to be syllable-timed.

We calculated Ramus et al'.s measures from our data to provide a direct comparison between the PVI, applied to vowel length and %V, ΔV and ΔIV. The results are given in Table 3 below. The BE and SE values given were calculated on the basis of the sentences in the reduced vowel set, which are comparable to Ramus et al'.s English sentences which contain full and reduced vowels.

In Table 3, our SE and BE data have been added to Ramus et al's results (see Table 1 in Ramus et. al., 1999). Ramus et al. sorted the data in their table in ascending order by %V; the measure they suggest captures most successfully the traditional grouping into stress-timed and syllable-timed languages. Note that in Ramus et al's table, the data were measured in seconds, and multiplied by 100 for ease of reading. We have done the same to allow for direct comparisons.

Note in addition, however, that the values obtained for our BE data and Ramus et al's English data are extremely comparable especially for the categories %V and ΔV. This suggests that when we apply Ramus et al's methods to our data, we obtained values which are highly comparable.

Our data shed doubt on the reliability of %V as an indicator of rhythm classes. Table 3 shows that %V does not reflect the rhythmic differences between our British English and our Singapore English data and the English data analyzed by Ramus et al. (taken from British English; Franck Ramus, p.c.). Moreover, the data in Table 3 appear to show that there are no rhythmic differences between Singapore English and British English, despite

TABLE 3

Combination of Ramus et. al (1999) results with data from the present paper, sorted by %V in ascending order

Language	*%V*		*ΔV*		*ΔIV*	
BE	**38.2**	**(5.0)**	**45.2**	**(15.8)**	**62.0**	**(17.3)**
SE	**39.25**	**(6.0)**	**39.25**	**(16.88)**	**89.4**	**(50.6)**
English	40.1	(5.4)	46.4	(12.5)	53.5	(16.3)
Polish	41.0	(3.4)	25.1	(6.7)	51.4	(11.8)
Dutch	42.3	(4.2)	42.3	(9.3)	53.3	(15)
French	43.6	(4.5)	37.8	(12.1)	43.9	(7.4)
Spanish	43.8	(4.0)	33.2	(10)	47.4	(8.5)
Italian	45.2	(3.9)	40.0	(10.5)	48.1	(8.9)
Catalan	45.6	(5.4)	36.8	(14.4)	45.2	(8.6)
Japanese	53.1	(3.4)	40.2	(5.8)	35.6	(7.4)

TABLE 4

Combination of Ramus et al'.s findings and data from the present paper sorted in descending order by ΔV

Language	*%V*		*ΔV*		*ΔIV*	
English	40.1	(5.4)	46.4	(12.5)	53.5	(16.3)
BE	**38.2**	**(5.0)**	**45.2**	**(15.8)**	**62**	**(17.3)**
Dutch	42.3	(4.2)	42.3	(9.3)	53.3	(15)
Japanese	53.1	(3.4)	40.2	(5.8)	35.6	(7.4)
Italian	45.2	(3.9)	40.0	(10.5)	48.1	(8.9)
SE	**39.25**	**(6.0)**	**39.25**	**(16.88)**	**89.4**	**(50.6)**
French	43.6	(4.5)	37.8	(12.1)	43.9	(7.4)
Catalan	45.6	(5.4)	36.8	(14.4)	45.2	(8.6)
Spanish	43.8	(4.0)	33.2	(10)	47.4	(8.5)
Polish	41.0	(3.4)	25.1	(6.7)	51.4	(11.8)

suggestions of syllable-timing in the SE literature, and despite the cross-varietal differences in vowel reduction shown in the present paper.

Ramus et al's second measure, ΔV (standard deviation of vocalic intervals), is the one which is closest to our PVI measure. Sorted by ΔV, and in descending order (assuming that stress-timed languages exhibit the highest level of variability), Table 4 reflects the difference between SE and BE. Note that the ΔV ordering also accounts for the absence of vowel reduction in Polish, that is, with respect to vocalic intervals, Polish behaves like a syllable-timed language (cf. Ramus et. al., 1999). In Table 3 above, which is sorted by %V, Polish, which does not have vowel reduction, is placed next to English, which has extensive vowel reduction.

If we sort the data by Ramus et al's third measure, the standard deviation of intervocalic intervals (descending order), SE and BE are grouped together again. Table 5 shows

TABLE 5

Combination of Ramus et al'.s findings and data from the present paper sorted in descending order by ΔIV

Language	*%V*		*ΔV*		*ΔIV*	
SE	**39.25**	**(6.0)**	**39.25**	**(16.88)**	**89.4**	**(50.6)**
BE	**38.2**	**(5.0)**	**45.2**	**(15.8)**	**62**	**(17.3)**
English	40.1	(5.4)	46.4	(12.5)	53.5	(16.3)
Dutch	42.3	(4.2)	42.3	(9.3)	53.3	(15)
Polish	41.0	(3.4)	25.1	(6.7)	51.4	(11.8)
Italian	45.2	(3.9)	40.0	(10.5)	48.1	(8.9)
Spanish	43.8	(4.0)	33.2	(10)	47.4	(8.5)
Catalan	45.6	(5.4)	36.8	(14.4)	45.2	(8.6)
French	43.6	(4.5)	37.8	(12.1)	43.9	(7.4)
Japanese	53.1	(3.4)	40.2	(5.8)	35.6	(7.4)

that in our SE data, the standard deviation of intervocalic intervals was considerably higher than in the BE data; in fact, among the languages shown in the table, SE exhibits the highest intervocalic variability overall.

The grouping of SE and BE by ΔIV at one end of the continuum is not surprising; we investigated two varieties of English, which differ primarily in the degree of vowel reduction, and our data were segmentally matched; that is, we ensured that the consonantal environments surrounding the vowels in our test sentences were comparable. Segmental differences between SE and BE have been widely documented in the literature (for discussion see Brown, 1991; or Deterding,1994b). The magnitude of the difference in ΔIV between SE (89.4) and BE (62) in Table 5, on the other hand, is considerable, and leads us to question the reliability of the intervocalic measure ΔIV. The data in Table 5 suggest that the intervocalic variability in SE is 1.4 times higher than in BE, whereas the vocalic variability is 1.1 times lower. These data do not reflect the impression of syllable-timing in SE which has been described in the literature, and they illustrate the drawbacks of the standard deviation as a measure of variability (see Figure 1 in the present paper). Earlier, we argued that the standard deviation reflects spurious variability introduced by between-speaker differences in articulation rate as well as changes in articulation rate within a sentence, and that the PVI improves on the standard deviation because the PVI is cumulative, controls for changes in speaking rate within intonation phrases, and contains an articulation rate normalization component. The PVI values for the intervocalic intervals in our SE and BE data are given in Figure 14, and support our point. The data in Figure 14 suggest that the difference between SE and BE is based on differences in the vocalic intervals, not intervocalic intervals; a finding which reflects the impressionistic comments in the literature about syllable-timing in Singapore English.

We conclude that the PVI is indeed a better measure of rhythmicity than the standard deviation, and that a combination of PVI values for vocalic and consonantal intervals takes us some way towards an adequate account of rhythmic differences between languages. Note that the superiority of the PVI is not an artifact of our data as we had pointed out earlier that the values we had obtained for our BE data was highly comparable to the values obtained

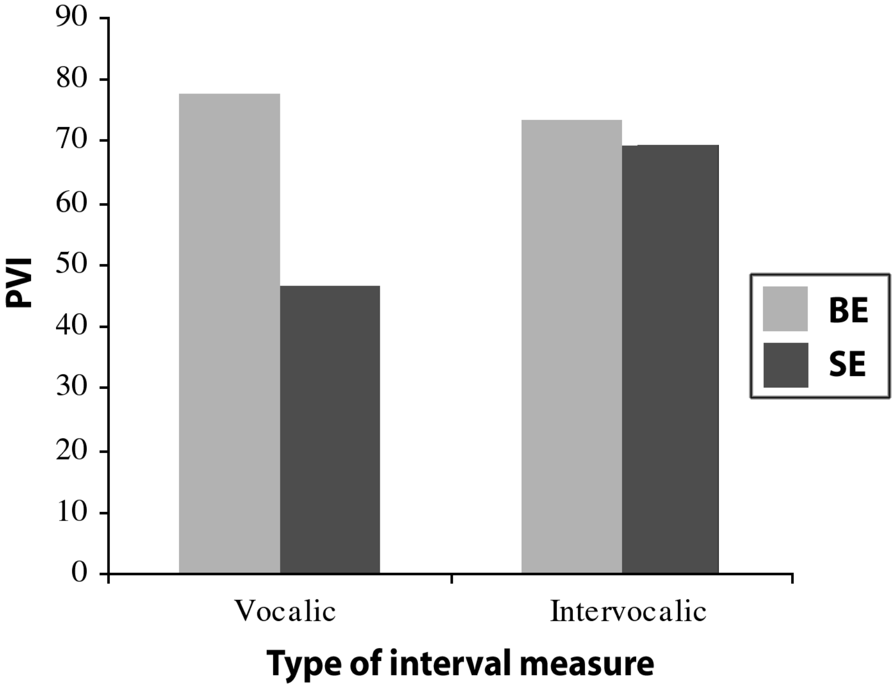

Figure 14

PVI values for vocalic and consonantal intervals in our SE and BE data (reduced vowel set)

for Ramus et. al's English data. Our data show that the rhythm of SE differs from that of BE because it involves less variability in vocalic intervals. Other languages may exhibit differences in their intervocalic intervals, and yet others may differ from each other in both types of interval.

SUMMARY AND CONCLUSION

In the present study, we have compared the acoustic correlates of rhythm in British English, which is said to be stress-timed, and Singapore English, which is said to be syllable-timed. We hypothesized that an investigation of vowels would provide us with an account of the cross-varietal difference, and we examined vowel duration, and spectral patterning. We predicted that successive vowels would be more nearly equal in duration in SE than in BE, and that vowel reduction in SE would differ from vowel reduction in BE. Our findings supported our predictions. The data revealed (1) a cross-varietal difference in the patterning of successive vowel durations; and (2) a cross-varietal difference in the spectral patterning of full and reduced vowels. Data from SE exhibited significantly less variability between successive vowels than data from BE; and full and reduced vowels pattern more peripherally in SE than in BE. To conclude, we discuss our findings in turn, beginning with the vowel quality data.

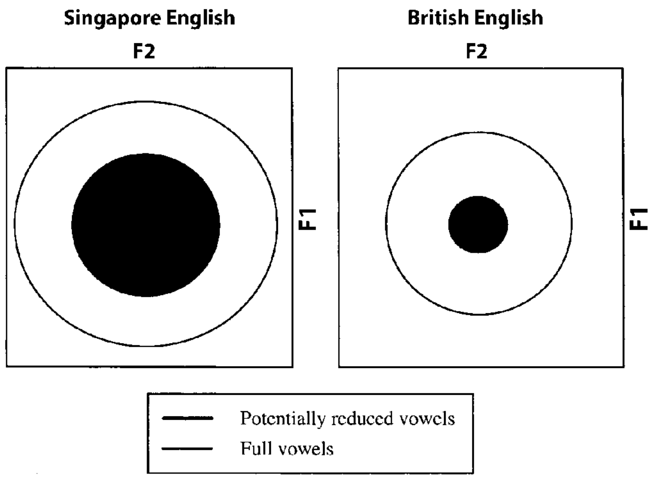

Figure 15

Patterning of full and reduced vowels in SE (left panel) and BE (right panel)

Our findings for vowel quality illustrate the language and variety-specificity of the distinction between full and reduced vowels. Speakers of Singapore English and British English make a distinction between full and reduced vowels, but the distinction is different in nature; in SE, the distinction is more peripheral in the F1/F2 space than it is in BE. Figure 14 illustrates this finding schematically.

Figure 15 shows that although the spectral characteristics of a reduced vowel in SE may be very similar to those of a full vowel in BE, one cannot conclude that SE does not have vowel reduction. SE speakers make a distinction between full and reduced vowels, but the distinction involves a different area of the vowel spectrum.

Our duration data have methodological implications. The data show that measurements of time intervals can provide us with an acoustic correlate of stress- or syllable timing in different varieties of English, provided one measures vowel durations, rather than syllable durations, and provided that the results are quantified relatively, rather than absolutely. The means of quantification we have proposed and used in this study is the "Pairwise Variability Index," or PVI, a measure which captures the degree of variability in sequences of acoustic data.[5]

Since the completion of the present study, the Pairwise Variability Index has been applied to a comparison of rhythmic patterns in English and French adults and four-year-olds (Grabe, Post, & Watson, 1999).[6] Grabe and colleagues showed that the PVI reflects the rhythmic differences between French, which is said to be syllable-timed and General Southern British English, which is said to be stress-timed; PVI values for French adult speakers were significantly smaller than for English adult speakers. Secondly, the PVI

5 The application of the rhythm index is not restricted to duration data; Low (1998) has shown that the index may also be applied to the investigation of other acoustic correlates of rhythm, such as vowel amplitude.

6 Following Mehler et al. (1996), Ramus et al. (1999) propose that infant speech perception is focused on vowels. Our proposal does not contradict their hypothesis; Infants' perception of speech rhythm might be determined by a combination of the degree of variability in successive vocalic intervals, and the degree of variability in the intervals between vocalic sections.

revealed a cross-linguistic difference in the acquisition of rhythm. At age four, French children produce similar PVI values to their mothers, but the PVI values of English children are significantly smaller than those of their mothers, suggesting that a stress-timed rhythm may be more difficult to acquire than a syllable-timed rhythm.

Finally, we compared the PVI as an indicator of rhythmicity with a set of measures proposed by Ramus et al. (1999). We concluded that the PVI is a better indicator of rhythmicity than either of the measures suggested by Ramus et al., and that the application of the PVI to Ramus et al's intervocalic interval measure may provide a better indicator of rhythmic class than the vocalic PVI alone. A combined PVI measure may capture the rhythmic characteristics of languages such as Polish or Catalan which have posed a problem for the traditional stress-timing versus syllable-timing dichotomy (Ramus et al., 1999).

In these languages, the level of variability in vocalic and intervocalic intervals may be complementary. Polish might exhibit high variability in intervocalic intervals, a characteristic which it shares with stress-timed languages, but the variability between vocalic intervals may be low, and point towards syllable-timing. Catalan may differ from Spanish in vocalic intervals, but not in intervocalic intervals (i.e., Catalan has vowel reduction, but Spanish does not; cf. Ramus et al., 1999). These predictions indicate the need for a comprehensive survey of rhythm types in the world's languages using the PVI measure.

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APPENDIX

Full Vowel Set

1. John came back through France last Sunday.
2. Don seemed quite cross with John last week.
3. Paul drives past huge towns by highway.
4. Jane gets four by post each Thursday.
5. Grace works through huge mounds each Friday.

Reduced Vowel Set

1. John was sick of Fred and Sandy.
2. Don was across at Jonathan's.
3. Paula passed her trial of courage.
4. Jane has four to last the winter.
5. Grace was tired of Matthew Freeman.