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English words on the Procrustean bed: Polysyllabic shortening reconsidered

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ABSTRACT

The polysyllabic shortening hypothesis holds that the duration of a primary stressed syllable is inversely proportional to the number of additional syllables within the word. We examine the evidence for this process in British English speech by measuring the duration of primary stressed syllables in monosyllabic, disyllabic and trisyllabic words, both right-headed series – e.g. *mend*, *commend*, *recommend* – and left-headed series – e.g. *mace*, *mason*, *masonry*. In contrast with some of the original studies of polysyllabic shortening (e.g. Lehiste, 1972), we record target words both when carrying nuclear pitch accent and when unaccented. As in previous studies, we find strong evidence of polysyllabic shortening in accented words, an effect of comparable magnitude in right-headed and left-headed words. In unaccented words, polysyllabic shortening is minimal or absent, but there is evidence, supporting previous studies, of domain-edge effects localised to specific sub-syllabic constituents. Unlike these effects, which occur on both pitch-accented and unaccented words, polysyllabic shortening of the primary stressed syllable in these data is confined to pitch-accented words.

1. Introduction

In Greek mythology, Procrustes was a bandit who dragged his kidnap victims back to his lair and tied them to the bed. He had a strict "one size fits all" policy: short captives were stretched to fit the length of the bed; tall ones had their legs cut down to size. The Procrustean bed approach has been much in evidence in theories of speech timing, particularly for Germanic languages like English. The isochrony hypothesis proposed that stress-delimited feet in English are of equal duration (e.g. Abercrombie, 1967), which requires stretching or compression where feet are composed of different numbers of syllables or segments. Similarly, the polysyllabic shortening hypothesis proposes that sub-constituents of words are stretched or compressed towards preservation of relative uniformity of word length (e.g. Lehiste, 1972).

There is a broad class of speech timing processes that are well-supported, which may be glossed as "lengthening at important points in the signal". Lengthening at the edges of domains is well-attested, in particular, word-initial lengthening (e.g. Cooper, 1991; Fougeron & Keating, 1997; Oller, 1973) and phrase-final lengthening (e.g. Klatt, 1975; Oller, 1973; Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992). Some studies have reported a word-final lengthening effect (e.g. Beckman & Edwards, 1990; Klatt, 1973; Oller, 1973), although whether this occurs in the absence of higher-level boundaries or phrasal stress remains uncertain (e.g. Harris & Umeda, 1974; Turk & Shattuck-Hufnagel, 2000). Accentual lengthening – the greater duration of segments within phrasally stressed, pitch-accented words – may be counted another such process (e.g. Sluijter, 1995; Turk & Sawusch, 1997; Turk & White, 1999), affecting the stressed syllable and other parts of phrasally stressed words.

Procrustean processes such as stress-based isochrony and polysyllabic shortening posit durational adjustments of a different nature, essentially suggesting an inverse relationship between the length of some constituent, such as the word or the foot, and the duration of some sub-constituent, e.g. segment or syllable. A parsimonious model of speech timing should posit the minimum number of different types of durational effect necessary to explain observed durational data, so given that stress-based isochrony is not well-supported empirically (e.g. Dauer, 1983), the status of Procrustean processes in general may also be questionable. In particular, much of what has been described as polysyllabic shortening may be explainable in terms of other, better-supported effects, e.g. accentual lengthening, initial lengthening and final lengthening.

A primary purpose of this paper therefore is to reconsider the so-called polysyllabic shortening in contexts where other durational effects are likely to be absent or controlled. For example, in comparisons of disyllabic vs trisyllabic words, initial lengthening on [m] is unlikely in, e.g. *commend* vs. *recommend*, and accentual lengthening is absent when the word bears no pitch accent. A shorter [mɛnd] duration in unaccented *recommend* as compared

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to *commend*, all else being equal, would be unambiguous evidence for polysyllabic shortening, lending support to the view that it is a fundamental process in English speech timing.

In addition, we consider how the lengthening of constituents in pitch-accented words (accentual lengthening) may mediate the relationship between word length and the duration of the primary stressed syllable, given that most previous findings of polysyllabic shortening have examined accented words only. We also assess the possible role of word-final lengthening in observed polysyllabic shortening. To do this, we compare the effect of word length on the primary stressed syllable in sequences with final stress ("right-headed" words – e.g. ˈ*mend*, *co*ˈ*mmend*, *reco*ˈ*mmend*) and sequences with initial stress ("left-headed" words – e.g. ˈ*mace*, ˈ*mason*, ˈ*masonry*). In right-headed words, final lengthening of the primary stressed syllable is expected regardless of word length, and so should be a constant factor, whereas in left-headed words, final lengthening on the primary stressed (initial) syllable is expected to attenuate the further this syllable is from the end of the word (e.g. Wightman et al., 1992).

1.1. Polysyllabic shortening in English

It has long been asserted that there is an inverse relationship between word size and sub-constituent duration in English speech. Jones (1942–3, p. 10) stated that the duration of English long vowels in primary stressed syllables is strongly affected by the number of following unstressed syllables within the word. Lehiste (1972) and Port (1981) found evidence for this, showing that the stressed vowel in words such as *speed*, *speedy*, *speedily* was progressively shorter as word length increased. (Except where otherwise stated, all findings discussed here concern American English speech.) These studies considered only left-headed words (i.e. those beginning with a stressed syllable) and utilised a fixed frame sentence, in which the only variation between successive sentences was the test word itself. For example, Port (1981) presented nonsense words such as *dib*, *dibber* and *dibberly* in the fixed sentence *I say [target word] again every Monday*. This context would be expected to elicit a nuclear pitch accent on the target word, as the only new information in successive sentences. Furthermore, Lehiste and Port – in common with polysyllabic shortening researchers such as Barnwell (1971), Klatt (1973) and Nakatani, O'Connor, and Aston (1981) – did not control phrase length or the alignment of the stressed syllable with constituent boundaries.

Given these aspects of experimental design, the interpretation of such results remains ambiguous. Firstly, where evidence regarding polysyllabic shortening is only obtained from accented words, the possibility remains that the effect depends on the presence of phrasal pitch accent. Secondly, because the word length manipulation in these experiments was accomplished by adding a syllable to the word, and thus also to the phrase and utterance, it is not clear whether results from these studies really demonstrate a Procrustean effect at the word-level. The domain of such an effect could equally be a higher-level constituent dominating the word, or indeed a lower-level constituent, such as a within-word constituent beginning with a stressed syllable. Thirdly, unless the alignment of the measured syllable with word and phrase boundaries is controlled, observed Procrustean effects may be confounded with domain-edge lengthening: for example, the difference between *speed* and *speedy* in a phrase-final context could be due to the relative attenuation of final lengthening in the stressed syllable in the context of the longer word.

Turk and Shattuck-Hufnagel (2000; see also Beckman & Edwards, 1990) addressed the potential confounds implicit in many earlier studies, looking for evidence of polysyllabic shortening in monosyllables and disyllables beginning and ending with matched stressed syllables (e.g. left-headed *tune* vs *tuna*; right-headed *choir* vs *acquire*). They attempted to control extraneous influences, such as phrase length and alignment with phrase boundaries, by placing these words in near-homophonous phrase pairs (e.g. *tune acquire* vs *tuna choir*), within carrier sentences. They found evidence for some polysyllabic shortening in the stressed syllables of both left-headed and right-headed words, although this effect appeared to be greater in left-headed (e.g. *tuna*) than right-headed words (e.g. *acquire*) and greater in all words when pitch-accented. They concluded that a combination of word-initial lengthening (Cooper, 1991; Fougeron & Keating, 1997; Oller, 1973), accentual lengthening (Sluijter, 1995; Turk & Sawusch, 1997; Turk & White, 1999), syllable ratio equalisation (Abercrombie, 1965; Albrow, 1968) and polysyllabic shortening best accounted for their results in American English (see Turk & Shattuck-Hufnagel, 2000, for a full description and review of the evidence for these processes).

By examining both left-headed and right-headed words, and by controlling the length of the carrier phrase, Turk and Shattuck-Hufnagel's study specifically targeted the influence of *word* length on sub-constituent duration. Their results did, however, raise some questions deserving of further study, in particular, concerning the link between accentual lengthening and polysyllabic shortening.

1.2. Accentual lengthening and polysyllabic shortening

When the primary stressed syllable of a word carries a pitch accent, it undergoes substantial lengthening, manifest on all sub-constituents of the syllable (Sluijter, 1995; Turk & Sawusch, 1997; Turk & White, 1999). Turk and White, in a study of contrastive pitch accent in Scottish English, found this lengthening was greater in a monosyllable than in a disyllable: thus, for example, [ni] shows 23% accentual lengthening in the monosyllable *knee* but only 16% in the disyllable *kneecap*. Given this attenuation of accentual lengthening in disyllables as compared to monosyllables, stressed syllables will be longer in pitch-accented monosyllables than in pitch-accented disyllables, even in the absence of a more general inverse relationship between word length and stressed syllable duration. Turk and Shattuck-Hufnagel (2000) also found that polysyllabic shortening appeared greater when words were pitch-accented, reinforcing the possibility of a link between accentual lengthening and observed polysyllabic shortening.

1.3. Lengthenings, shortenings and the derivation of segment duration

Durational mechanisms are traditionally described in terms of lengthenings and shortenings, terms which imply the adjustment of default durations. The adjustment-of-a-default view is not readily distinguished on the basis of data currently available from another type of view, in which surface durational patterns result from the simultaneous influence of a variety of abstract, structural factors (e.g. position, phrasal stress, number of syllables in a word, etc.). The main goal of our paper is to distinguish Procrustean effects, where surface durations depend on the number of subunits within a larger unit, from other types of effects, such as edge effects and durational patterns due to the presence of phrasal pitch accent. We frequently refer to these effects in traditional terms (e.g. polysyllabic shortening, final lengthening, etc.), but our use of these terms should not be taken to imply that we endorse an adjustment-of-a-default view.

1.4. Purpose of the current experiment

A comparison between monosyllables and disyllables, such as in Turk and Shattuck-Hufnagel (2000), makes disentangling domain-edge and Procrustean effects problematic: if a stressed syllable is spoken in the context of a monosyllabic word, both initial and final lengthening may operate to increase its duration relative to a disyllable. For example, [tun] in *tune* is word-final and its rhyme may be longer than that of [tun] in *tuna*. Similarly, [kwaɪr] in *choir* is word-initial, and therefore its onset is expected to be longer than the onset of [kwaɪr] in *acquire*. In the current experiment, we aim to distinguish domain-edge durational effects from the influence of polysyllabic shortening by looking at sequences of monosyllables, disyllables and trisyllables, both when pitch-accented and when unaccented. Comparisons of disyllables and trisyllables in particular (e.g. *commend* vs *recommend*, *mason* vs *masonry*) will control for several potential word-edge confounds. Evidence of comparable polysyllabic shortening in right-headed and left-headed words, both when accented and unaccented, may be taken as a clear demonstration of a Procrustean process; specifically, an inverse relationship between word length and sub-constituent duration. If this relationship is found to be strongly influenced by the presence of pitch accent, or differentially distributed in right-headed and left-headed words, it weakens the status of polysyllabic shortening as a speech timing mechanism with general applicability.

2. Experimental method

2.1. Participants

Three females and three males took part in the recordings, all undergraduate or postgraduate students of the University of Edinburgh, with no known speech or hearing disorders. Four of the participants were judged to be speakers of standard southern British English; two speakers manifested perceptible influences from their background in the north of England. Participants were paid for each of three recording sessions. They were not given any specific information about the purpose of the recordings until after they had completed all of them.

2.2. Experimental design

The main dependent variable in this experiment was the duration of the primary stressed syllable ("test syllable") in monosyllabic, disyllabic and trisyllabic words. The experiment used sixteen different test syllables, each spoken in three different lexical contexts: monosyllable, disyllable and trisyllable. There were eight keyword triads in which the test syllable was always word-initial, the "left-headed" keywords, for example: *mace*, *mason*, *masonry*. There were eight keyword triads in which the test syllable was always word-final, the "right-headed" keywords: for example, *mend*, *commend*, *recommend*. The full set of keywords is shown in Table 1. Many of the right-headed trisyllables could be regarded as containing an initial secondary stress (e.g. *ˌcondeˈscend*), whereas most of the left-headed words comprise a stressed syllable followed by two unstressed syllables. This asymmetry is an inevitable consequence of English morphophonology: trisyllabic words with final primary stress that could not carry a secondary stress on the first syllable are rare to non-existent. However, most prosodic theories would regard both left-headed and right-headed lexical words containing a single root morpheme – like those used here – as comprising single prosodic words: the main debates concern the prosodic nature of function words and whether higher prosodic words are formed from compound lexical words or from the combination of lexical words with other constituents (e.g. Nespor & Vogel, 1986; Selkirk, 1996).

Table 1
Experimental keywords. *Note*: *juice* and the final syllables of *produce* and *reproduce* are homophonous in the accents of British English recorded in the present study: /ɹi.pɹə.dʒus/.

Left-headed keyword triads			Right-headed keyword triads		
cap	captain	captaincy	juice	produce	reproduce
dog	dogma	dogmatist	main	humane	inhumane
fish	fissure	fisherman	mend	commend	recommend
mace	mason	masonry	port	report	misreport
part	partner	partnership	pose	compose	decompose
speck	spectre	spectacle	pose	dispose	indispose
sense	censor	censorship	pose	suppose	presuppose
ten	tendon	tendency	send	descend	condescend

Table 2
Example carrier sentences. Keywords are underlined, and the words to be emphasised in the unaccented keyword condition are in block capitals.

Left-headed keywords	Right-headed keywords
I SAW the mace unreclaimed AGAIN	JOHN saw Jessica mend it AGAIN
I SAW the mason reclaimed it ALL	JOHN saw Jessie commend it AGAIN
I SAW the masonry cleaned AGAIN	JOHN saw Jess recommend it AGAIN

Keywords were presented to participants in sentences designed to be read as meaningful utterances. Example sentences are shown in Table 2. The full set of sentences is listed in Appendix 1.

The intended placement of pitch accent was controlled by writing particular words in block capitals and instructing participants to emphasise the capitalised words. In the accented condition, the target words themselves were emphasised; as the final accents in the phrase, these were nuclear accents. In the unaccented condition, one word towards the start of the sentence was realised with a prenuclear accent, and one word towards the end of the sentence was produced with a nuclear accent. (As discussed below, care was taken to ensure that sentences were realised as single intonational phrases.) Words to be emphasised in the unaccented condition never immediately preceded the test syllable, as the word following an accented word may manifest a small amount of residual lengthening (Turk & White, 1999). As there is a range of possible locations for accents within utterances, this use of capitalisation to indicate phrasal stress did not require participants to deviate further from a normal speaking style than is inherent in a sentence-reading task.

The number of syllables in each utterance was kept constant by adding extra syllables to the frame sentence to counterbalance for fewer syllables in disyllabic or monosyllabic keywords. To minimise utterance-edge effects, the distance of test syllables from utterance boundaries was kept constant within each keyword triad and keywords were separated from the ends of the carrier sentence by at least two syllables.

The immediate phonetic environment of the test syllable was kept constant, as far as possible, as shown in Table 2 and Appendix 1. The syllable immediately following the test syllable in the left-headed triads and immediately preceding the test syllable in the right-headed triads was unstressed, whether within the same word or within an adjacent content word, or comprised an adjacent function word, for example: *Kate GAVE the sense of the SCRIPT away* vs *Kate GAVE the censor the SCRIPT again* (target words are underlined here for illustration purposes only). This was to control the possible lengthening effect of stress adjacency on the test syllable (e.g. Bolinger, 1965).

Care was taken in the recordings to prevent the placement of prosodic phrase boundaries adjacent to the keywords, because of the possible confounding impact of higher-level domain-edge lengthening effects on word-level processes. Because the relationship between syntax and prosody is not deterministic, sentences cannot be written which elicit a particular phrasing consistently, so the approach taken was to eliminate the well-established durational effects of intonational phrase boundaries, whilst allowing variation in the placement of boundaries of such lower-level constituents as may exist, and which may have durational consequences.

Intonational phrase boundaries were controlled in a number of ways. Firstly, the experimental sentences were relatively short, and free of any syntactic structures associated with obligatory intonational phrase construction. Secondly, as utterance-internal pauses are most strongly associated with intonational phrase boundaries, participants were instructed to read each experimental sentence without pausing. Thirdly, each recorded utterance was listened to, and those with perceptible intonational phrase boundaries adjacent to the experimentally significant words were excluded from analysis.

The lack of specific measures to control the placement of phrase boundaries below the level of the intonational phrase has consequences for the interpretation of the experimental findings with regard to word-edge effects. The edges of some experimentally significant words may coincide with boundaries of, for example, phonological phrases; therefore, word-initial or word-final lengthening effects could be attributed, at least in part, to phrase boundaries rather than word boundaries. This proviso is considered further in the discussion of the experimental results.

2.3. Elicitation and recording

There were a total of 96 experimental sentences (16 keywords $\times$ 3 sentences $\times$ 2 accent conditions). These were presented to participants along with another 288 similarly constructed sentences relating to other experiments, in three blocks of similar size (between 112 and 136 sentences per block). There were three recording sessions for each participant, one for each block, with the order of presentation of the blocks counterbalanced between participants. Within a recording session, all the sentences in the block were presented twice, in a different random order each time. Participants were not made aware of any systematic grouping or repetition of sentences.

Sentences were displayed one at a time in the centre of a Sun workstation monitor. Before the first recording, participants were instructed to read aloud the sentences as they appeared on the screen and to emphasise the words in capital letters, speaking naturally and without pausing mid-sentence. The rate of presentation of the sentences was controlled by participants. Participants were given a short practice before each session and then read all the sentences from one block twice, with opportunities for breaks within and between blocks if required. Each recording session lasted around half an hour.

Participants were asked to repeat sentences during the recording if the lexical content of the sentence was misread, if the words in capitals were not emphasised, if words not in capitals were emphasised or if a pause was perceived within the utterance.

Recordings were made direct to disk in ESPS format at a sample rate of 16 kHz. All of the recordings are available for download in the Edinburgh University Speech Timing Archive and Corpus of English (White & King, 2003).

2.4. Measurement of test syllable sub-constituent duration

Recordings were analysed on a SPARCstation using XWaves. Analysis was a two-stage process: firstly, assessment of utterance production; secondly, measurement of the duration of the test syllable constituents in each utterance.

Utterances were excluded from measurement on the basis of a number of production criteria: if the words of the sentences were misread or pronounced inconsistently with other readings by the same participant of the same keywords; if the keyword was accented in the unaccented condition; if the keyword was not accented in the accented condition; if the stress pattern in polysyllables was non-canonical (e.g. ˈ*reproduce* rather than *repro*ˈ*duce*); if an intonational phrase boundary was perceived adjacent to the keyword. Judgement of the placement of accents and boundaries was primarily perceptual, but reference was also made to the waveform and spectrogram of the utterance; visual inspection of fundamental frequency contours was often inconclusive, partly because of their commonly discontinuous nature. There were 18 utterances for which both repetitions were excluded from measurement, thus missing data points represented 3.1% of the total.

The start and end points of the sub-syllabic constituents of each test syllable – onset, nucleus, coda – were labelled by visual inspection of the waveform and spectrogram, with occasional reference to auditory criteria. For consistency, labelling was performed keyword-by-keyword, with the keyword tokens in random order for each speaker and the order of speakers random for each keyword. Vowels were taken as beginning with the appearance of formant structure in the spectrogram along with coherent periodicity in the waveform. Thus, aspiration following the release of voiceless stops was included within the duration of the consonant. (Note that some other studies, e.g. Turk and Shattuck-Hufnagel, 2000, and Turk, Nakai, & Sugahara, 2006, do not include the aspiration interval in onset consonant duration.) Vowels were taken to end with the appearance of significant consonant constriction, as indexed by attenuation of pitch periods, appearance of frication, etc., according to context. Specific details of the measurement procedure are given in Appendix 2.

For consistency, singleton test syllable coda consonants (e.g. [s] in *mace, mason, masonry*), which could be regarded as ambisyllabic or as unstressed syllable onsets in left-headed disyllables and trisyllables (e.g. *mason, masonry*), were always labelled as codas. Coda stop consonants were sometimes difficult to measure reliably: the codas of right-headed *port* and left-headed *cap, dog, part* and *speck* were all occasionally elided or glottalised. These words were thus excluded from all analyses which included coda duration, including whole syllable duration.

2.5. Statistical analysis

Clark (1973) advocated the use of the minF′ statistic, derived from by-subjects (F_1) and by-items (F_2) analyses, in language experiments of particular designs, for instance, where items are a nested factor within each experimental condition. In recent reporting of linguistic experiments of various designs, a common practice has been to regard differences as significant if both the F_1 and F_2 analyses attain the significance threshold. Raaijmakers, Schrijnemakers, and Gremmen (1999) argued, however, that this practice arises from a misinterpretation of Clark's recommendations, and further proposed that by-subjects analysis alone is appropriate for experiments where items are matched between conditions.

Following guidelines of Clark (1973) and Raaijmakers et al. (1999) we report minF′ for the initial analysis of syllable duration, where items are nested under Word Type (right-headed vs left-headed). Subsequent analyses are carried out separately for right-headed and left-headed words, thus items are matched between conditions (Accent and Word Length) and a by-subjects analysis is appropriate, with differences described as significant if $p<.05$, highly significant if $p<.01$ and approaching significance if $.05 \leq p<.10$.

3. Results: stressed syllable duration

Our main analyses are concerned with whole primary stressed syllable durations. For the reasons outlined above, all reported ANOVAs apart from the first are by subjects: Accent (accented vs unaccented) and Word Length (monosyllabic vs disyllabic vs trisyllabic) are within-subjects factors. Word Type (left-headed vs right-headed) is a further within-subjects factor in the first reported ANOVA. Subsidiary analyses of the duration of subconstituents of test syllables are reported subsequently, to provide a fuller picture of the range of durational effects operating within the word-level domain.

3.1. Stressed syllable duration: word types pooled

Mean primary stressed syllable duration for right-headed keywords is shown in Fig. 1 and for left-headed keywords in Fig. 2. An ANOVA incorporating both the right-headed keywords (all except *port*) and the left-headed keywords (*fish*, *mace*, *sense*, *ten*) showed a main effect of Accent [$minF'(1,6)=18.78$, $p<.005$], in line with previous findings showing that stressed syllables are longer when accented than when unaccented. There was a main effect of Word Length [$minF'(2,26)=29.19$, $p<.001$], consistent with the polysyllabic shortening hypothesis. The near-significant main effect of Word Type [$minF'(1,10)=3.64$, $p=.086$] is not, in itself, theoretically interesting: English does not furnish sufficient examples to allow comparison between identically constituted test syllables in right-headed and left-headed monosyllable vs disyllable vs trisyllable series, and so durational differences between series can be attributed to variation in test syllable composition.

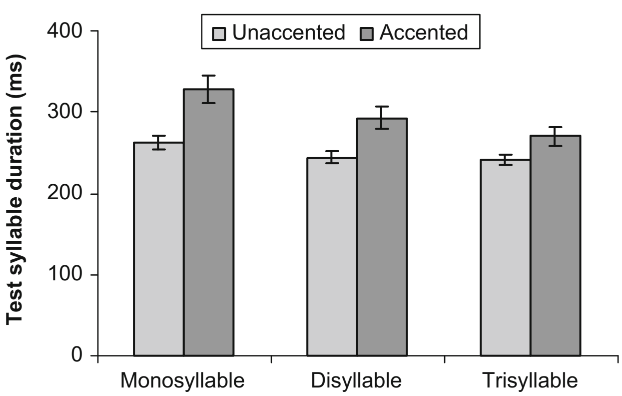

Fig. 1. Mean test syllable duration (ms) for all right-headed keyword triads excluding *port*.

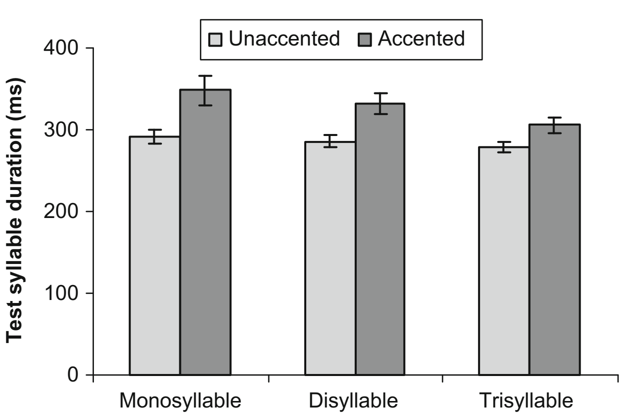

Fig. 2. Mean test syllable duration (ms) for the left-headed keyword triads *fish*, *mace*, *sense* and *ten*.

There was no significant interaction between Word Type and Accent [$minF'(1,12)=.55$, n.s.], consistent with the view that the degree of accentual lengthening of the primary stressed syllable is relatively insensitive to word structure (left-headed vs right-headed), with the caveat that right-headed vs left-headed series differed in test syllable composition. There was a significant interaction between Accent and Word Length [$minF'$ $(2,20)=13.72$, $p<.001$] and the interaction between Word Type and Word Length approached significance [$F'(2,22)=2.59$, $p<.098$]: both of these results indicated that the relationship between stressed syllable duration and word length is not as straightforward as the simple effect of Word Length might suggest. In particular, the mean durations shown in Figs. 1 and 2 indicate that the inverse relationship between primary stressed syllable duration and word length is strongly supported only for accented keywords. There was no significant three-way interaction, Word Type × Word Accent × Word Length [$F'(2,22)=1.16$, n.s.].

There is clear potential for asymmetry of durational variation between right-headed words and left-headed words, arising, for example, from domain-edge processes such as word-initial lengthening. Given this and the near-significant interaction between Word Length and Word Type, separate ANOVAs were conducted for right-headed and left-headed words.

3.2. Stressed syllable duration: right-headed words

For the duration of the test syllables in right-headed words, there were significant effects of Word Length [$F(2,10)=39.64$, $p<.001$] and Accent [$F(1,5)=31.16$, $p<.005$] and a significant interaction between Word Length and Accent [$F(2,10)=25.17$, $p<.001$]. Planned paired samples comparisons (one-tailed) indicated that the difference in test syllable duration between monosyllables and disyllables was significant for both accented and unaccented keywords [accented: 35 ms, 11%, $t(5)=8.73$, $p<.001$; unaccented: 18 ms, 7%, $t(5)=7.89$, $p<.001$]; however, the difference between disyllables and trisyllables (e.g. [mɛnd] in *commend* vs. *recommend*) was only significant for accented keywords [22 ms, 8%, $t(5)=3.45$, $p<.01$]. Fig. 3 shows the magnitude and statistical significance of the durational difference in these four cases, indicating clearly that polysyllabic shortening is greater, even in proportional terms, in accented than unaccented words.

3.3. Stressed syllable duration: left-headed words

There were likewise significant effects of Word Length and Accent on the duration of the test syllables in left-headed keywords. Thus, test syllables were shorter in words containing more syllables: [$F(2,10)=12.82$, $p<.005$], and were longer in accented words [$F(1,5)=15.81$, $p<.05$]. The interaction between Word Length and Accent was also significant [$F(2,10)=7.58$, $p=.01$]. Planned paired samples comparisons (one-tailed) indicated that the difference in test syllable duration between monosyllables and disyllables (e.g. [meɪs] in *mace* vs *mason*) approached significance for accented keywords [16 ms, 5%, $t(5)=1.74$, $p=.07$], and was significant for unaccented keywords [6 ms, 2%, $t(5)=2.16$, $p<.05$]; the difference between disyllables and trisyllables (e.g. [meɪs] in *mason* vs *masonry*) was significant for both accented and unaccented keywords [accented: 26 ms, 8%, $t(5)=4.54$, $p<.005$; unaccented: 7 ms, 3%, $t(5)=2.27$, $p<.05$].

As shown in Fig. 3, there is evidence of a Procrustean effect in both accented and unaccented words, but both absolute and proportional polysyllabic shortening is much greater in accented words. Thus, for example, [meɪs] was longer in *mace* than in *mason* (mean: 6 ms, 2% unaccented; 16 ms, 5% accented) and longer in *mason* than in *masonry* (mean: 7 ms, 3% unaccented; 26 ms, 8% accented).

The fact that the durational difference in accented words between monosyllables and disyllables did not quite attain significance at the .05 level, despite its relative magnitude (16 ms, 5%), may be attributed to the somewhat reduced power in the analyses for whole left-headed syllables. This is as a result of the difficulty of consistently measuring the coda stop consonants in the *cap*, *dog*, *part* and *speck* series, which led to them being excluded from the whole syllable analyses. The analyses of syllable nucleus duration (reported below) include these series, however, and here the shortening in accented words is shown to be statistically robust.

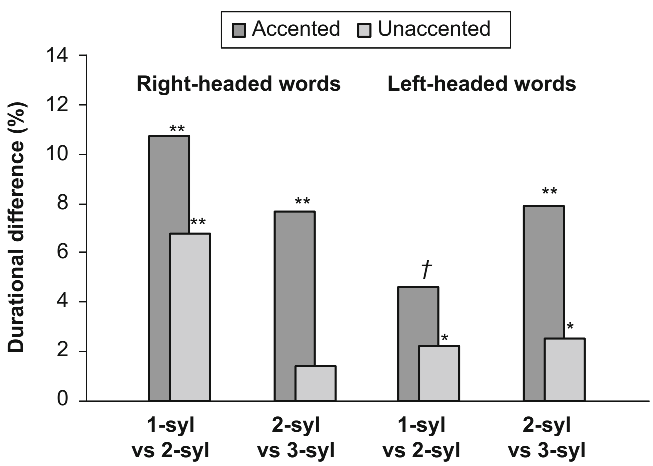

Fig. 3. Mean durational differences for primary stressed syllables in monosyllables vs disyllables and disyllables vs trisyllables. In each comparison, the percentage is the durational difference proportional to the duration in the longer word. Significance levels of effects: †.1 < p < .05; *p < .05; **p < .01 (all t-tests one-tailed).

3.4. Stressed syllable duration: between-speaker comparison

As stated above, we had a somewhat heterogeneous participant pool, with two speakers having regional accents from the north of England and the other four speaking standard southern British English. To check that main effects and interactions were comparable across speakers, we performed two further ANOVAs, with fixed factors of Word Length, Accent and Speaker. For both right-headed words and left-headed words, as in the above analyses, there were main effects of Accent [Right-Headed (R-H): $F(1,419)=217.85$, $p<.001$; Left-Headed (L-H): $F(1,229)=108.54$, $p<.001$] and Word Length [R-H: $F(2,419)=51.63$, $p<.001$; L-H: $F(2,229)=15.49$, $p<.001$], and an interaction between Accent and Word Length [R-H: $F(2,419)=10.28$, $p<.001$; L-H: $F(2,229)=4.26$, $p<.05$]. Unsurprisingly, there was a main effect of Speaker [R-H: $F(5,419)=39.49$, $p<.001$; L-H: $F(5,229)=18.77$, $p<.001$], and also an interaction between Accent and Speaker [R-H: $F(5,419)=7.43$, $p<.001$; L-H: $F(5,229)=6.89$, $p<.001$], the latter indicating that the magnitude of accentual lengthening varies between speakers. There was no interaction between Word Length and Speaker [R-H: $F(10,419)=1.38$, n.s.; L-H: $F(10,229)=1.21$, n.s.] and, crucially, no three-way interaction between Accent, Word Length and Speaker [R-H: $F(10,419)=.43$, n.s.; L-H: $F(10,229)=.55$, n.s.], indicating that the greater effect of Word Length on stressed syllable duration in accented words was consistent across speakers.

As Fig. 4 shows, the two speakers from the north of England showed the attenuation of polysyllabic shortening in unaccented words to a very similar degree to the four speakers from the south of England, and for both sets of speakers, the effects can be seen for both right-headed and left-headed words.

3.5. Stressed syllable duration: summary

With regard to the polysyllabic shortening hypothesis, the key findings from the analyses of stressed syllable duration are

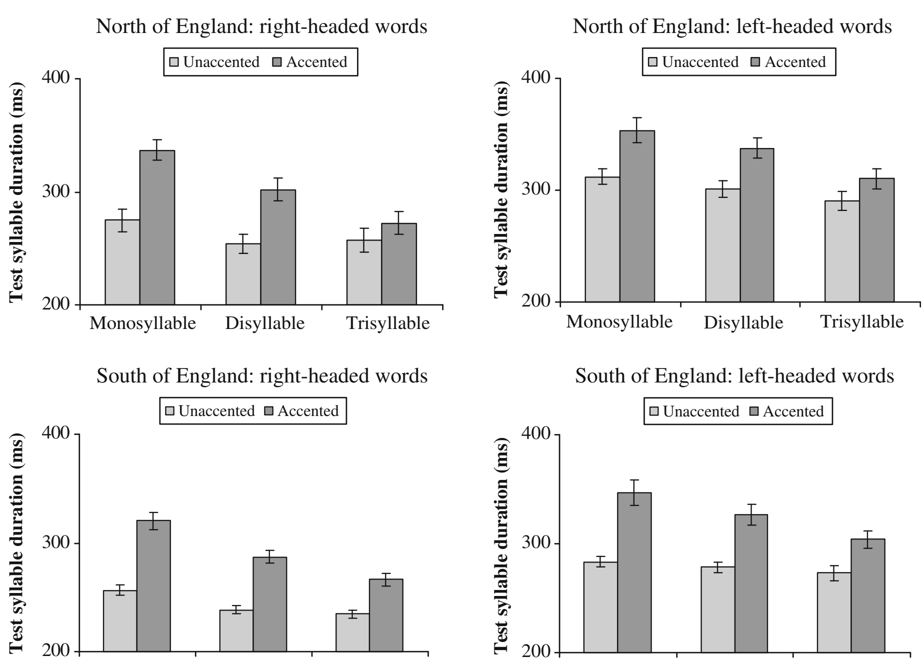

Fig. 4. Mean test syllable duration (ms) broken down by speaker region of origin (north of England vs south of England). Means for right-headed keyword triads exclude *port*; means for left-headed keyword triads based on *fish*, *mace*, *sense* and *ten*.

as follows:

- There is a clear polysyllabic shortening effect in pitch-accented words, as shown in Fig. 3. This effect is evident both in right-headed series, like *mend*, *commend*, *recommend*, and in left-headed series, like *mace*, *mason*, *masonry*. In both cases, the primary stressed syllable is longest in monosyllabic words, shorter in disyllabic words and shorter still in trisyllabic words.
- The evidence for polysyllabic shortening is much weaker in unaccented words. Firstly, as shown in Fig. 3, the pattern is not consistent: the polysyllabic shortening hypothesis predicts a clear inverse relation between word length and stressed syllable duration, but this is only evident in left-headed words (e.g. *mace*, *mason*, *masonry*). In unaccented right-headed words (e.g. *mend*, *commend*, *recommend*), there is shortening from monosyllables to disyllables, but not from disyllables to trisyllables. Secondly, the size of the polysyllabic shortening effect, where present in unaccented words, is lower in all cases than the comparable effect in accented words. In three out of four comparisons in Fig. 3, the proportional shortening in the unaccented case is less than half of that in the accented case.
- The exceptional case of a relatively large shortening in unaccented words is from monosyllable to disyllable in the right-headed series (e.g. from *mend* to *commend*). This is paralleled by the largest polysyllabic shortening effect in the accented case, also from monosyllable to disyllable in the right-headed series. Thus, for example, [mɛnd] is longer in *mend* than *commend* (mean: 18 ms, 7% unaccented; 35 ms, 12% accented). A possible interpretation of this parallel effect in accented and unaccented words is the well-attested phenomenon of word-initial lengthening (e.g. Cooper, 1991; Fougeron & Keating, 1997; Oller, 1973). We explore this possibility further below, by examining sub-syllabic constituent durations, and indeed find that the shortening from monosyllable to disyllable is localised on the stressed syllable onset, in accordance with previous reports of word-initial lengthening.
- Left-headed keyword series (e.g. *mace*, *mason*, *masonry*) do manifest a relatively small polysyllabic shortening effect in the unaccented case (7 ms, 3%). Analysis of the duration of sub-syllabic constituents, reported below, indicates that the locus of this effect in unaccented left-headed keywords is the syllable nucleus. In the subsequent discussion, we explore the possibility that this effect is related to word-final lengthening (e.g. Beckman & Edwards, 1990; Klatt, 1975; Oller, 1973).

3.6. Discussion: word length and the distribution of accentual lengthening

As discussed above, for the analysis of polysyllabic shortening the comparison between disyllables and trisyllables is the more informative because the monosyllable vs disyllable comparison may be influenced by word-edge effects. Polysyllabic shortening is quite clear in accented keywords between disyllables and trisyllables: thus [mɛnd] was shorter in *recommend* than in *commend* (22 ms, 8%) and [meɪs] was shorter in *masonry* than in *mason* (26 ms, 8%). For stressed syllables in unaccented words, there is no evidence of test syllable shortening between *commend* and *recommend*, and the test syllable durational difference between *mason* and *masonry*, while statistically reliable, is less than a third of that seen in accented words (7 ms vs 26 ms).

Thus, there is a clear relationship between word-level shortening in polysyllables and lengthening due to pitch accent. As all the ANOVAs reported above confirm, there was very strong and consistent evidence of lengthening of stressed syllables in pitch-accented words compared with unaccented words (see Figs. 1 and 2). The magnitude of the accented-related effect was, however, modulated by word length. Fig. 5 shows the mean accentual lengthening effect in test syllables according to word length, based on the difference in syllable duration between the accented and unaccented condition. The attenuation of accentual lengthening in longer words is apparent, as is the relative symmetry of the effect: the amount of accentual lengthening of primary stressed syllables in right-headed disyllables and trisyllables such as *commend* and *recommend* was equivalent to that in left-headed disyllables and trisyllables such as *mason* and *masonry*.

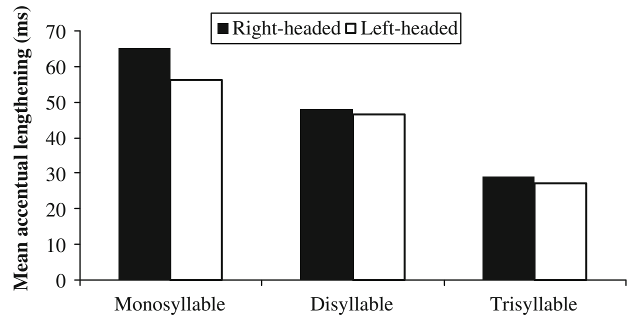

Fig. 5. The magnitude of accentual lengthening of the primary stressed syllable in monosyllables, disyllables and trisyllables, relative to the same syllable in unaccented words. All right-headed keywords are included except *port*; left-headed keywords included are *fish*, *mace*, *sense* and *ten*.

Turk and White (1999) also observed this attenuation of accentual lengthening in polysyllables and here its significance for the interpretation of polysyllabic shortening becomes clear. Rather than a Procrustean effect, polysyllabic shortening in accented words may arise because the extra duration that stressed syllables receive due to pitch accent is less in disyllables than in monosyllables, and even less in trisyllables.

It is known that unstressed syllables in polysyllabic words can be affected by accentual lengthening: Sluijter (1995) and Turk and White (1999) both found that accentual lengthening also affects unstressed syllables in disyllabic words: in left-headed words like *thankful* or *kneecap*, the syllable following the stressed syllable was lengthened (whether unstressed or carrying a secondary stress); in right-headed words like *fulfil* or *capsize*, the syllable preceding the stressed syllable was likewise lengthened regardless of stress, although to a lesser degree. Turk and White (1999) also showed that both unstressed syllables in left-headed trisyllables like *catapult* were lengthened, with the word-final syllable lengthened more than the medial syllable, and White (2002) showed that word-initial syllables not carrying a primary stress are lengthened in right-headed words like *recommend*. Turk and White (1999) presented some evidence of residual lengthening across a word boundary following an accented syllable, but this effect was small compared, for example, to the lengthening of a syllable following an accented syllable within a word.

These studies clearly demonstrate that accentual lengthening can affect the whole lexical word: the primary stress consistently shows the most lengthening; the word-final syllable also tends to show a substantial degree of lengthening, while there is variation between studies in the degree of lengthening of non-word-final unstressed syllables (e.g. Turk & Dimitrova, 2007, showed that the second and third syllables of words like *presidency* are not always lengthened when the word is accented). One interpretation of the polysyllabic attenuation of primary stressed syllable accentual lengthening, discussed further below, is that is it due to the redistribution of lengthening amongst additional syllables in longer words.

4. Results: sub-syllabic durational effects

The above results show a clear relationship between polysyllabic shortening and pitch accent. In all cases, polysyllabic shortening was much greater in accented than unaccented words. However, there were cases of residual polysyllabic shortening in unaccented words, as shown in Fig. 3: a relatively large (18 ms) shortening effect between monosyllables and disyllables (e.g. *mend* vs *commend*) in right-headed words; a small shortening effect monosyllables to disyllables to trisyllables in left-headed words (e.g. *mace* vs *mason* vs *masonry*: 6 ms monosyllable to disyllable; 7 ms disyllable to trisyllable). Here we look at durational trends in the phonological constituents of the stressed syllable (onset, nucleus, coda), to consider the loci of these shortening effects in unaccented words.

Mean durations of sub-syllabic constituents of the primary stressed syllable are shown in Table 3, and the results of by-subjects ANOVAs with within-subjects factors of Word Length (monosyllable, disyllable, trisyllable) and Accent (pitch-accented, unaccented) are shown in Table 4. The analyses indicate that Accent consistently affects all sub-syllabic constituents of the primary stressed syllable in both right-headed and left-headed words. The interaction between Word Length and Accent, significant or approaching significance in almost all cases, can be seen in Table 3 to relate to the fact that the polysyllabic shortening effect observed in accented words is consistently attenuated or absent for unaccented words. (The exceptional case where no interaction is observed – syllable nucleus, right-headed words – relates to the anomalous slight *lengthening* of the nucleus in accented disyllables compared with monosyllables, for which we have no explanation.)

The main effect of Word Length on sub-syllabic constituent duration is somewhat less consistent across constituent types, and must be interpreted in light of the crucial dependence of significant polysyllabic shortening on the presence of accent. This is more clearly demonstrated by the pairwise comparisons reported in Table 5 between monosyllables and disyllables or between disyllables and trisyllables for unaccented and accented keywords: in only five out of twelve comparisons for sub-syllabic constituent duration is there a significant or near-significant durational difference in the unaccented case. In one case (coda: right-headed disyllable vs trisyllable), the effect does not quite attain significance and is, in any case, extremely small (2 ms). Of the other four cases, two relate to differences in onset duration between monosyllables and disyllables (right-headed and left-headed), and the other two relate to differences in nucleus duration in left-headed words (monosyllables vs disyllables and disyllables vs trisyllables).

In addition to accentual lengthening, the results suggest a large word-initial lengthening effect, with a syllable onset locus.

Table 3
Mean primary stressed subsyllabic constituent durations (ms) and standard errors (in parentheses). Coda results are for all right-headed keywords except *port* and for left-headed keywords *fish*, *mace*, *sense* and *ten*.

	Number of syllables in word		
	1	2	3
Onset duration of primary stressed syllable: right-headed keywords			
Unaccented	99 (4)	83 (3)	81 (2)
Accented	129 (8)	98 (5)	85 (4)
Onset duration of primary stressed syllable: left-headed keywords			
Unaccented	105 (3)	99 (2)	101 (2)
Accented	128 (7)	120 (6)	117 (6)
Nucleus duration of primary stressed syllable: right-headed keywords			
Unaccented	97 (3)	97 (4)	97 (4)
Accented	115 (4)	118 (5)	111 (5)
Nucleus duration of primary stressed syllable: left-headed keywords			
Unaccented	88 (4)	83 (3)	75 (3)
Accented	101 (4)	90 (3)	81 (3)
Coda duration of primary stressed syllable: right-headed keywords			
Unaccented	69 (5)	68 (4)	66 (3)
Accented	85 (7)	81 (6)	76 (5)
Coda duration of primary stressed syllable: left-headed keywords			
Unaccented	104 (5)	105 (5)	106 (5)
Accented	130 (11)	126 (8)	115 (5)

Table 4
Results of analyses of variance for subsyllabic constituent durations. Coda analyses are based on all right-headed keywords except *port* and for left-headed keywords *fish*, *mace*, *sense* and *ten*.

Word length	Accent	Accent × Word Length
Onset duration: right-headed words		
$F(2,10)=65.90$, $p<.001$	$F(1,5)=36.69$, $p<.005$	$F(2,10)=22.57$, $p<.001$
Onset duration: left-headed words		
$F(2,10)=7.20$, $p<.05$	$F(1,5)=12.99$, $p<.05$	$F(2,10)=3.27$, $p=.081$
Nucleus duration: right-headed words		
$F(2,10)=2.11$, n.s.	$F(1,5)=13.19$, $p<.05$	$F(2,10)=2.53$, n.s.
Nucleus duration: left-headed words		
$F(2,10)=51.73$, $p<.001$	$F(1,5)=6.96$, $p<.05$	$F(2,10)=7.15$, $p<.05$
Coda duration: right-headed words		
$F(2,10)=5.31$, $p<.05$	$F(1,5)=28.91$, $p<.005$	$F(2,10)=8.17$, $p<.01$
Coda duration: left-headed words		
$F(2,10)=1.98$, n.s.	$F(1,5)=9.15$, $p<.05$	$F(2,10)=5.32$, $p<.05$

Table 5
Mean differences according to word length for subsyllabic constituent durations and results of planned paired samples comparisons (one-tailed). Coda analyses are based on all right-headed keywords except *port* and for left-headed keywords *fish*, *mace*, *sense* and *ten*. (NB: *indicates a two-tailed comparison, as the durational trend was in the opposite direction to that predicted by the polysyllabic shortening hypothesis, i.e. nucleus duration was here greater in disyllables than monosyllables.)

	Monosyllable vs disyllable	Disyllable vs trisyllable
Onset: right-headed words		
Accented	31 ms, 32%; $t(5)=9.39$, $p<.001$	13 ms, 15%; $p(5)=3.08$, $p<.05$
Unaccented	16 ms, 20%; $t(5)=13.03$, $p<.001$	n.s.
Onset: left-headed words		
Accented	8 ms, 7%; $p(5)=2.42$, $p<.05$	n.s.
Unaccented	6 ms, 6%; $p(5)=4.40$, $p<.005$	n.s.
Nucleus: right-headed words		
Accented	−4 ms, −3%; $t(5)=2.29$, $p=.071$*	8 ms, 7%; $t(5)=1.95$, $p=.055$
Unaccented	n.s.	n.s.
Nucleus: left-headed words		
Accented	11 ms, 12%; $t(5)=4.77$, $p<.005$	9 ms, 11%; $t(5)=8.42$, $p<.001$
Unaccented	5 ms, 6%; $t(5)=3.49$, $p<.01$	8 ms, 11%; $t(5)=6.66$, $p<.001$
Coda: right-headed words		
Accented	5 ms, 6%; $t(5)=2.62$, $p<.05$	4 ms, 5%; $t(5)=1.64$, $p=.082$
Unaccented	n.s.	2 ms, 3%; $t(5)=1.93$, $p=.056$
Coda: left-headed words		
Accented	n.s.	11 ms, 9%; $t(5)=2.71$, $p<.05$
Unaccented	n.s.	n.s.

Results consistent with polysyllabic shortening are observed mainly for accented words. The exception (nucleus duration in unaccented left-headed words, e.g. longer [eɪ] in *mason* as compared to *masonry*) may be accounted for if we assume that word-final lengthening can affect a penultimate stressed syllable nucleus, as discussed below. An alternative account we also consider in the general discussion is that polysyllabic shortening of stressed syllable nuclei for unaccented words is more likely when initial lengthening is not available to signal their position with respect to the word boundary.

4.1. Discussion: evidence for word-initial lengthening

Syllable onsets had greater duration word-initially than word-medially, as shown by the comparison between right-headed monosyllables and disyllables (e.g. *mend* vs *commend*) in Table 3. This effect was consistently observed in both accented words (31 ms; 32%) and unaccented words (16 ms; 19%), and supports previous studies such as Oller (1973) and Cooper (1991) in which lengthening of the syllable onset was observed in word-initial position relative to word-medial position.

If the durational difference between *mend* and *commend* results from polysyllabic shortening in addition to initial lengthening, we would expect to see durational differences on the nucleus and/or coda. However, this is not observed in the absence of pitch accent. The characterisation of word-initial lengthening as a localised effect is supported by Fougeron and Keating (1997), Turk and Shattuck-Hufnagel (2000) and Byrd (2000) who found that lengthening does not extend beyond the word-initial syllable onset (including aspiration in the case of voiceless stops). In fact, in the present data, the syllable nucleus was actually slightly shorter in accented right-headed monosyllables than disyllables (e.g. *mend* vs *commend*; 4 ms, 3%), an effect which approached significance.

Finally with regard to word-initial lengthening: it should be noted that, for left-headed triads (e.g. *mace*, *mason*, *masonry*), the onset duration was slightly greater in monosyllables than in disyllables and trisyllables (e.g. [m] was longer in *mace* as compared to *mason*/*masonry*), even in unaccented words (6 ms; 6%). Although this suggests some localised support for polysyllabic shortening, there is no equivalent durational difference in onset duration between left-headed disyllables and trisyllables (*mason* vs *masonry*). This result could indicate that word-initial lengthening has lesser magnitude in polysyllables than in monosyllables, but we will refrain from further interpretation here.

4.2. Discussion: evidence for word-final lengthening?

Left-headed words showed a significant effect of word length on stressed syllable nucleus duration: as shown in Table 5, nucleus duration was greater in left-headed monosyllables than in disyllables (e.g. [eɪ] in *mace* vs *mason* – mean: unaccented 5 ms, 6%; accented 11 ms, 12%). Nucleus duration was also greater in disyllables than trisyllables (e.g. [eɪ] in *mason* vs *masonry* – mean: unaccented 8 ms, 11%; accented 9 ms, 11%). These results provide support for the polysyllabic shortening hypothesis, and unlike most of the foregoing, the evidence here suggests an effect in both accented and unaccented keywords. However, the polysyllabic hypothesis predicts a parallel word length effect in the nuclei of right-headed unaccented triads, which is certainly not found (see Table 5 for both results). In addition, the distribution of the word length effect appears to be different in accented left-headed words as compared to right-headed words: in accented left-headed words, the nucleus shows the greatest word length effect (e.g. *mace*, *mason*, *masonry*); in contrast, for accented right-headed words (e.g. *mend*, *commend*, *recommend*), the word length effect is more evenly distributed across onset, nucleus and coda. This pattern of results indicates a possible combination of polysyllabic attenuation of accentual lengthening (all parts of the syllable being lengthened under pitch accent, e.g. Turk & Sawusch, 1997), and an additional effect localised on the nucleus. These effects are similar to observed effects in the literature. Previous studies of polysyllabic shortening, which used only left-headed keywords (Lehiste, 1972; Port, 1981) found that the syllable nucleus showed the greatest effect: thus, [i] is shortened in the sequence *sleep*, *sleepy*, *sleepiness* more than the coda [p]. Similarly, Oller (1973) found evidence for a word-final lengthening effect, which appeared greater on the syllable nucleus than on the coda. Of course, given the high probability that the test words in these previous experiments were accented, it is difficult to separate the attenuation of accentual lengthening in polysyllables – clearly demonstrated above – from any independent effect of word position.

Turk and Shattuck-Hufnagel (2000) also found that the syllable centre was the sub-syllabic component showing the greatest durational effect in comparisons of left-headed words, e.g. *tune* vs *tuna*.[1] Because they did not observe final lengthening effects on the syllable coda in their words (e.g. [n] in *tune* was not significantly different from [n] in *tuna*), and because [ə] duration in e.g. *tuna* was no different from [ə] in e.g. *acquire*, they did not interpret this effect on the stressed syllable nucleus as word-final lengthening. Instead, they interpreted it as a syllable ratio equalisation effect (Abercrombie, 1965; Albrow, 1968) that operated in addition to other effects, e.g. polysyllabic shortening and word-initial lengthening.

Could the localised word length effect on the syllable nucleus in series such as *mace*, *mason*, *masonry* be interpreted as evidence of word-final lengthening? At the phrasal level, final lengthening affects the rhyme of the phrase-final syllable (Berkovits, 1994; Wightman et al., 1992), but can also affect the rhyme of the final stressed syllable when this is not in absolute-final position (e.g. Turk & Shattuck-Hufnagel, 2007). If word-final lengthening is analogous to phrase-final lengthening, we would expect e.g. longer [eɪ] and [s] in *mace* as compared to *mason*, and possibly longer [eɪs] in *mason* as compared to *masonry*. Here, we observed the expected durational differences on the syllable nucleus, but not on the coda.[2] Turk and Shattuck-Hufnagel (2000) observed a similar pattern (lengthening on the syllable centre, but not on the coda in e.g. *tune* vs. *tuna*) and on this basis rejected the final lengthening view. However, the word-final lengthening view could be salvaged if word-final lengthening affects a different locus than phrase-final lengthening, that is, if word-final lengthening affects the nucleus, whereas phrase-final lengthening affects the rhyme. Given the greater duration of [eɪ] in *mason* than in *masonry*, the word-final lengthening effect would, on this view, extend to the stressed syllable when in penultimate position, as observed for phrase-final lengthening, though in both cases, the greatest effect is on the stressed vowel in the final syllable. One perceptual reason for the localisation of the word-final lengthening on the nucleus of the stressed syllable rather than the

[1] Note that in order to segment their materials reliably, Turk and Shattuck-Hufnagel divided their measured stressed syllables into the first consonant, the last consonant, and the vocalic nucleus plus remaining consonants, the latter being termed the "syllable centre". Thus, where the onset or coda contained consonant clusters in their materials, the syllable centre was not isomorphic with the nucleus.

[2] The fact that the effect observed here does not include the coda consonant suggests that phrase-final lengthening is unlikely to be a confounding factor (i.e. participants were not systematically placing phrase boundaries following the test word).

rhyme (i.e. nucleus plus coda) might be to prevent lengthening of coda consonants being interpreted as word-initial lengthening (we are grateful to Rachel Smith for this observation). At higher levels, phrase-final lengthening of the rhyme is generally accompanied by a pre-boundary pitch excursion, which may serve to disambiguate the interpretation of lengthening in a manner that is not available at phrase-internal word boundaries.

An alternative description of the effect observed in unaccented left-headed nuclei is as a Procrustean effect within the word-rhyme, a constituent which can be defined as beginning with the nucleus of the primary stressed syllable and continuing to the word boundary, e.g. [eɪs] in *mace,* [eɪsən] in *mason*. What might be termed "word-rhyme compression" would be an inverse relationship between the number of syllables in the word-rhyme and the duration of the stressed syllable nucleus, and thus belonging to the class of hypothesised Procrustean effects. We do not attempt to decide definitively between the word-final lengthening and word-rhyme compression interpretations here.[3]

5. General discussion

Like other studies in the literature (Lehiste, 1972; Port, 1981, etc.), we found that English stressed syllables may be shorter in words of more syllables, though the patterns of shortening vary according to word structure (left-headed vs right-headed words). And, like Turk and Shattuck-Hufnagel (2000), we found that these differences are greater in words bearing phrasal pitch accent than in unaccented words. We now consider the mechanisms responsible for these differences.

Because our study included comparisons of stressed syllable durations both for monosyllables vs disyllables and for disyllables vs trisyllables, we were able to distinguish between domain-edge processes, and the dependency of duration on the number of subconstituents within a domain (what we call Procrustean processes, e.g. polysyllabic shortening). In general, Procrustean effects would be expected for both types of comparisons (disyllables vs trisyllables, as well as monosyllables vs disyllables), whereas domain-edge effects should be most clearly manifest in monosyllabic vs disyllabic comparisons and localised within the syllable.

A general role for domain-edge processes was supported by fewer significant differences for disyllables vs trisyllables as compared to monosyllables vs disyllables. Unambiguous evidence for a word-initial edge effect was observed for right-headed unaccented words. For example, initial [m] is longer in e.g. *mend* where it is word-initial, than in *commend*, where it is medial. For these types of words, disyllabic vs trisyllabic differences were not observed, and therefore Procrustean explanations for the difference in [m] duration are less likely. The word-initial domain-edge effect appears to account for all of the difference in stressed syllable duration between e.g. *mend* and *commend* in unaccented right-headed words.

Results consistent with polysyllabic shortening were observed for all accented words, and for left-headed unaccented words (e.g. *mace*, *mason*, *masonry*). However, any explanation of these findings must account both for the fact that effects in accented words were substantially greater in magnitude than effects in unaccented words, and for the fact that, in the unaccented case, right-headed words (e.g. *commend*, *recommend*) did not show durational patterns consistent with polysyllabic shortening.

Can we explain our findings without any recourse to polysyllabic shortening? One possibility is to account for them using two other types of attested mechanisms, domain-edge lengthening effects and accentual lengthening. Another possibility is that polysyllabic shortening exists, as a mechanism for providing information for the listener regarding word structure, but it only applies where other mechanisms, such as word-initial lengthening, are not informative. We now consider the evidence for these two interpretations in turn.

5.1. Accentual lengthening and domain-edge lengthening

Given that (a) accentual lengthening of the primary stressed syllable diminishes in longer words and (b) the evidence for polysyllabic shortening *per se* in unaccented words is very weak, it may be that most of observed polysyllabic shortening arises from differences in the magnitude of accentual lengthening in monosyllables, disyllables and trisyllables. In studies which have shown polysyllabic shortening in English, such as Lehiste (1972) and Port (1981), it is highly likely that the measured words were pitch-accented, and therefore such results appear compatible with the attenuation of accentual lengthening view. In addition, both Lehiste and Port examined series of left-headed words only, such as *speed*, *speedy*, *speedily*. As the present results suggest a word-final lengthening effect localised to the nuclei of stressed syllables, the results of Lehiste and Port, which showed the greatest word-level effect on the nucleus and smaller effects on the onset and coda, are compatible with a combination of attenuation of accentual lengthening in polysyllables (potentially affecting the whole syllable) and word-final lengthening (localised on the nucleus). Likewise, the results found here for right-headed words like *mend*, *commend*, *recommend* are compatible with attenuation of accentual lengthening, together with word-initial lengthening in both accented and unaccented primary stressed syllables (e.g. [m] in *mend* vs *commend*).

Accentual lengthening is known to affect all parts of the stressed syllable (e.g. Turk & Sawusch, 1997), a finding clearly supported by the evidence presented here (see Table 4), and so attenuation of accentual lengthening might, in principle, be expected to be likewise distributed. The crucial disyllable vs trisyllable comparison, wherein immediate word boundary effects are controlled, indicates, however, that this attenuation is not evenly distributed (see Table 5): in right-headed words, the greatest shortening is on the onset (e.g. [m] in *commend* vs *recommend*), and in left-headed words, the greatest shortening is on the coda (e.g. [s] in *mason* vs *masonry*), with comparable shortening of the nucleus in left-headed and right-headed words. This greater attenuation on word-internal constituents may suggest that accentual lengthening tends to be preserved towards the edges of words. This pattern of attenuation may be linked to the fact that, as additional syllables are added to the word, these receive some of the accentual lengthening which in the monosyllable would be entirely located on the stressed syllable, as discussed in Section 3.6 above.

White (2002) outlined a domain-and-locus framework for English prosodic speech timing which incorporates domain-initial lengthening, domain-final lengthening and accentual lengthening, all considered as localised effects with phonologically defined loci. The distribution of lengthening within the loci depends on phonetic and phonological properties of its constituents, and may in some cases be discontinuous (see discussion of accentual

[3] It may be noted that there was durational evidence from a comparable set of data reported in White (2002) of word-final lengthening of unstressed syllables. Thus, the final syllables of *captain*, *censor*, *fissure*, *mason*, *spectre* and *tendon* were longer than the medial syllables of *captaincy*, *censorship*, *fisherman*, *masonry*, *spectacle* and *tendency*. This effect, comparable in accented and unaccented words (mean 33 and 25 ms, respectively), can clearly be interpreted as evidence of word-final lengthening, and thus supports that interpretation of the stressed syllable data. Reconciling these data to the word-rhyme compression interpretation is less straightforward.

lengthening above). Beyond the loci of these lengthening processes, there are no units which consistently impose timing constraints upon their sub-constituents. The clear prediction from this model, informed by the results reported here, is that localised lengthening effects constitute the strongest cues to speech structure for listeners. As well as word-initial and word/phrase-final lengthening effects, the attenuation of accentual lengthening in English polysyllables may serve as a cue to word structure for English listeners (e.g. Davis, Marslen-Wilson, & Gaskell, 2002; Salverda, Dahan, & McQueen, 2003).

Under this view, Procrustean effects are, at best, marginal. Thus, the finding by Turk and Shattuck-Hufnagel (2000) of a small difference in duration (6 ms, 4%) between stressed syllable nuclei in unaccented right-headed words (e.g. [ɪ] in *coffer bid* vs *caw forbid*), represents a challenge to the strong version of this hypothesis, as do findings of possible Procrustean effects in domains larger than the word (e.g. Rakerd, Sennett & Fowler, 1987; Kim, 2006). However, some such larger-domain effects may be reinterpreted within the domain-and-locus framework as localised lengthening effects, such as the lengthening of a stressed syllable when immediately followed by another stressed syllable. Whether the Procrustean bed has any place in English speech timing depends upon interpretations of small effects for which the evidence varies between dialects. It is clear that such effects, if they do exist, are minor compared to lengthening effects at important points in prosodic structure, specifically at prosodic boundaries and phrasal prominences.

5.2. *Polysyllabic shortening and signal redundancy*

An alternative to the localised lengthening effects view is that Procrustean effects, such as polysyllabic shortening, exist, but are only observed in certain domains and under particular circumstances. This view requires an explanation for the fact that polysyllabic shortening is limited to accented words and unaccented left-headed words, and for the fact that the differences observed on accented words are greater than those on unaccented words. A possible explanation may come from the Smooth Signal Redundancy hypothesis (Aylett, 2000; Aylett & Turk, 2004, 2006; Turk, in press), where prosodic structure mediates between predictability and the phonetic characteristics of utterances. On this view, prosodic structure has evolved to complement predictability (language redundancy), and directly controls acoustic saliency. Where language redundancy is high and words are highly predictable, there is no need to use prosodic structure to highlight or demarcate words. In English, phrasal stress (usually accompanied by pitch accent) is used to mark the new information in a sentence, and thus compensates for its unpredictability. Another prosodic mechanism that highlights unpredictable words is to signal their boundaries: speakers may control the duration of the stressed syllable according to the number of additional syllables in the word, thereby providing information about the location of the word boundary. We would therefore expect speakers to be more likely to signal the boundaries of phrasally stressed words, since these are the words that normally have low language redundancy. This view provides an explanation for the greater magnitudes of effects on accented words.

Even if we accept the view that accented words might be more likely than unaccented words to show polysyllabic shortening effects, we must still explain the different behaviour of left- vs right-headed unaccented words. That is, stressed syllable nucleus duration in unaccented words depends on number of syllables only for left-headed words (e.g. *mace*, *mason*, *masonry*), but not for right-headed words (e.g. *mend*, *commend*, *recommend*). One possibility is that, for right-headed words, the monosyllabic vs polysyllabic status of the words containing the stressed syllable is signalled by the duration of the onset consonant [m]. The word-initial lengthening mechanism is not available to signal the monosyllabic vs polysyllabic status of words containing e.g. [meɪs] (*mace*, *mason*, *masonry*). In these cases, speakers may therefore control the stressed syllable nucleus duration.

Note that this hypothesis does not explain the lack of durational differences for the stressed syllable in unaccented right-headed words (e.g. *commend* vs *recommend*). However, there does seem to be independent evidence suggesting that the use of the polysyllabic shortening mechanism may depend on the presence vs absence of other word boundary signalling mechanisms. For example, as discussed in the following section, polysyllabic shortening does not appear to occur in Finnish, where fixed word-initial stress provides a reliable word boundary cue (Suomi, 2007).

5.3. *Word length and accentual lengthening: cross-linguistic comparisons*

Most studies reporting polysyllabic shortening effects have examined English, but it is worth considering whether the relationship between accentual lengthening and polysyllabic shortening also applies to other languages. Studies of Swedish (Lindblom, 1968) and Dutch (Nooteboom, 1972) showed a small polysyllabic shortening effect on stressed vowel duration due to syllables preceding the main stressed syllable and a large effect due to syllables following the main stress. Examination of the materials suggests that the target words are highly likely to be accented: Lindblom used words in a fixed frame sentence, and Nooteboom reported stressed vowel duration in isolated words, and so these results are also compatible with a combination of the polysyllabic attenuation of accentual lengthening and word-final lengthening.

Suomi (2007) found no evidence of polysyllabic shortening in Finnish. The lack of an effect even in accented words probably relates to structural differences in the durational realisation of accent in Finnish compared with, for example, Dutch or English. All Finnish words have initial stress and the pitch movement on accented words is principally aligned with the first two morae (Suomi, Toivanen, & Ylitalo, 2003). It is these two morae that also show the greatest degree of accentual lengthening (in strongly accented words, there being no evidence of lengthening in words with weaker thematic accent). Suomi (2007) suggested that accentual lengthening in Finnish allows a consistent tonal movement whatever the segmental composition of the first two morae. The locus of the movement is thus always two morae long, so the distribution of accentual lengthening should not vary greatly between words. Minor durational adjustment processes might be expected according to the segmental characteristics of these first two morae, but the phonological quantity contrasts in Finnish may militate against this to some extent. It is also worth noting that Finnish fixed word-initial stress is a potentially strong word boundary cue for listeners, not present in a language like English.

6. Summary

The results of this experiment demonstrate that polysyllabic shortening as a consistent mechanism is confined to pitch-accented words. There is also evidence for two other processes associated with linguistic structure at the word-level, both with loci that can be defined in phonological terms. As previous studies have demonstrated, word-initial lengthening is a robust and relatively large effect, localised on the onset of the word-initial syllable. In addition, the nucleus of primary stressed syllable in left-headed words is longest in the monosyllable, shorter in the disyllable and shorter still in the trisyllable, even in unaccented words. We have considered interpretations of this finding either as word-final lengthening or as some form of Procrustean effect, and do not attempt to definitively adjudicate between them here.

A crucial aspect of these findings for subsequent work and for the interpretation of previous timing studies is that it is necessary always to consider a word's pitch accent status. Any durational effect, segmental or suprasegmental, can only be held to be reliable if it has been demonstrated in both accented and unaccented words.

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Appendix 1. Carrier sentences

Carrier sentences for left-headed keywords

John THREW the cap to the BED again.
John THREW the captain the BADGE again.
John THREW the captaincy BADGE again.
Kate GAVE the sense of the SCRIPT away.
Kate GAVE the censor the SCRIPT again.
Kate GAVE the censorship SCRIPT away.
Tim KNEW the dog may decline AGAIN.
Tim KNEW the dogma declined AGAIN.
Tim KNEW the dogmatist line AGAIN.
I SAW the fish again TODAY.
I SAW the fissure crack TODAY.
I SAW the fisherman TODAY.
I SAW the mace unreclaimed AGAIN.
I SAW the mason reclaimed it ALL.
I SAW the masonry cleaned AGAIN.
Jim LIKES his part no more than MOST.
Jim LIKES his partner more than MOST.
Jim LIKES his partnership the MOST.
I MADE the spec to collect WOOD.
I MADE the spectre collect WOOD.
I MADE the spectacle from WOOD.
I HEARD the ten denied AGAIN.
I HEARD the tendon go AGAIN.
I HEARD the tendency TODAY.

Carrier sentences for right-headed keywords

JOHN saw Jessica mend it AGAIN.
JOHN saw Jessie commend it AGAIN.
JOHN saw Jess recommend it AGAIN.
BETH saw Clematis pose it ALL.
BETH saw Clemmie dispose it ALL.
BETH saw Clem indispose it ALL.
I CHECKED in every port for TOM.
I CHECKED the old report for TOM.
I CHECKED the misreport for TOM.
GREG let big Oprah juice it ALL.
GREG let Bobbie produce it ALL.
GREG let Bob reproduce it ALL.
I LET the dancer pose it TODAY.
I LET the man suppose it TODAY.
I LET him presuppose it TODAY.
I SAW Widdicombe pose it AGAIN.
I SAW Jodie compose it AGAIN.
I SAW Joe decompose it AGAIN.
I MADE Burgundy send to them ALL.
I MADE Megan descend to them ALL.
I MADE May condescend to them ALL.
You MUST continue main treatment NOW.
You MUST maintain humane treatment NOW.
You MUST cease inhumane treatment NOW.

The words to be emphasised in the unaccented keyword condition are in block capitals. For clarity here, keywords are underlined, although they were not in the stimuli presented to participants. The requirement for phonetic balance in the environment of the test syllable, together with sentence length constraints, mean that some of the sentences are semantically rather strange. Participants appeared, however, to have no difficulty in reading these sentences with the same fluency as with the others. In some sentences, the requirement to maintain a consistent phonetic environment and the lack of segmentally appropriate counterbalancing words means that the syntactic structures of the sentences differ slightly within the keyword triads.

Appendix 2. Measurement of keyword constituent duration

A2.1. Measurement criteria

The location of speech segment boundaries was determined primarily by visual inspection of the speech waveform and a colour wideband spectrogram, applying the criteria given below. For consistent application of visual criteria, judgements were made using a window size of not less than 400 ms. Where alternative criteria are available for the determination of segment boundaries, a single criterion was applied to all examples of a particular keyword for a particular speaker. The parameters of application of certain criteria—for example, the choice of which formant break to associate with a given stop closure—were applied with similar consistency. Where labels are associated with the start or end of pitch periods, they were placed at the point of zero crossing on the waveform. Vowel-approximant and approximant-vowel sequences are particularly difficult to segment reliably and were avoided in the experimental materials.

Stop closure. The end of pitch period before a significant drop in waveform amplitude or at a break in a particular formant. Following a fricative, the drop in spectrogram energy intensity in a particular frequency range may be used.

Glottalised stop closure. The end of pitch period preceding a break in formant structure. A change in the shape of successive pitch periods may be taken as a guide: for example, lengthening or doubling.

Stop release. The start of waveform burst.

Vowel start/end. The start/end of a pitch period corresponding to appearance/disappearance of a particular formant, typically the second formant. The shape and magnitude of successive pitch periods may be also used as a guide.

Nasal start/end. The start/end of a pitch period corresponding to the appearance or disappearance of nasal formants on spectrogram. Where a nasal adjoins a vowel, the waveform amplitude minimum is usually a reliable criterion.

Fricative start/end. The start/end of continuous spectrogram energy in a particular frequency range. Additional criteria used for particular speakers and contexts include: the end/start of a particular preceding or following formant; the end/start of spectrogram voicing (for voiceless fricatives); a change in amplitude of waveform periodicity.

References

Abercrombie, D. (1965). A phonetician's view of verse structure. In: *Studies in phonetics and linguistics* (pp. 16–25). London: Oxford University Press.

Abercrombie, D. (1967). *Elements of general phonetics*. Edinburgh: Edinburgh University Press.

Albrow, K. H. (1968). *The rhythm and intonation of spoken English*. Programme in linguistics and English teaching paper no. 9, University College London.

Aylett, M. (2000). *Stochastic suprasegmentals – Relationships between redundancy, prosodic structure and care of articulation in spontaneous speech*. Ph.D. dissertation, University of Edinburgh.

Aylett, M., & Turk, A. (2006). Language redundancy predicts syllabic duration and the spectral characteristics of vocalic syllable nuclei. *Journal of the Acoustical Society of America*, *119*, 3048–3058.

Aylett, M., & Turk, A. E. (2004). The smooth signal redundancy hypothesis: A functional explanation for relationships between redundancy, prosodic prominence and duration in spontaneous speech. *Language and Speech*, *47*, 31–56.

Barnwell, T. P. (1971). *An algorithm for segment durations in a reading machine context*. Technical report 479, Research Laboratory of Electronics, Massachusetts Institute of Technology.

Beckman, M. E., & Edwards, J. (1990). Lengthenings and shortenings and the nature of prosodic constituency. In J. Kingston, & M. E. Beckman (Eds.), *Papers in laboratory phonology I: Between the grammar and the physics of speech* (pp. 152–178). Cambridge: Cambridge University Press.

Berkovits, R. (1994). Durational effects of final lengthening, gapping and contrastive stress. *Language and Speech*, *37*, 237–250.

Bolinger, D. (1965). *Forms of English: Accent, morpheme, order*. Cambridge, MA: Harvard University Press.

Byrd, D. (2000). Articulatory vowel lengthening and coordination at phrasal junctures. *Phonetica*, *57*, 3–16.

Clark, H. H. (1973). The language-as-fixed-effect fallacy: A critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behaviour*, *12*, 335–359.

Cooper, A. M. (1991). Laryngeal and oral gestures in English/p, t, k/. In *Proceedings of the XIIth international congress of phonetic sciences, Aix-en-Provence* (pp. 50–53).

Dauer, R. M. (1983). Stress-timing and syllable-timing reanalyzed. *Journal of Phonetics*, *11*, 51–62.

Davis, M. H., Marslen-Wilson, W. D., & Gaskell, M. G. (2002). Leading up the lexical garden path: Segmentation and ambiguity in spoken word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *28*, 218–244.

Fougeron, C., & Keating, P. A. (1997). Articulatory strengthening at edges of prosodic domains. *Journal of the Acoustical Society of America*, *101*, 3728–3740.

Harris, M. S., & Umeda, N. (1974). Effect of speaking mode on temporal factors in speech. *Journal of the Acoustical Society of America*, *56*, 1016–1018.

Jones, D. (1942–43). Chronemes and tonemes. *Acta Linguistica*, *3*, 1–10.

Kim, H. (2006). *Speech rhythm in American English: A corpus study*. Ph.D. Dissertation, University of Illinois at Urbana-Champaign.

Klatt, D. H. (1973). Interaction between two factors that influence vowel duration. *Journal of the Acoustical Society of America*, *54*, 1102–1104.

Klatt, D. H. (1975). Vowel lengthening is syntactically determined in a connected discourse. *Journal of Phonetics*, *3*, 129–140.

Lehiste, I. (1972). The timing of utterances and linguistic boundaries. *Journal of the Acoustical Society of America*, *51*, 2018–2024.

Lindblom, B. E. F. (1968). *Temporal organisation of syllable production*. Quarterly progress and status report 2-3/1968, Speech Transmission Laboratory, Stockholm.

Nakatani, L. H., O'Connor, K. D., & Aston, C. H. (1981). Prosodic aspects of American English speech rhythm. *Phonetica*, *38*, 84–106.

Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris Publications.

Nooteboom, S. G. (1972). *Production and perception of vowel duration: A study of durational properties in Dutch*. Ph.D. dissertation, University of Utrecht.

Oller, D. K. (1973). The effect of position in utterance on speech segment duration in English. *Journal of the Acoustical Society of America*, *54*, 1235–1247.

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

Raaijmakers, J. G. W., Schrijnemakers, J. M. C., & Gremmen, F. (1999). How to deal with "the language-as-fixed-effect fallacy": Common misconceptions and alternative solutions. *Journal of Memory and Language*, *41*, 416–426.

Rakerd, B., Sennett, W., & Fowler, C. A. (1987). Domain-final lengthening and foot-level shortening in spoken English. *Phonetica*, *44*, 147–155.

Salverda, A. P., Dahan, D., & McQueen, J. M. (2003). The role of prosodic boundaries in the resolution of lexical embedding in speech comprehension. *Cognition*, *90*, 51–89.

Selkirk, E. (1996). The prosodic structure of function words. In J. L. Morgan, & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 187–214). Mahwah, NJ: Lawrence Erlbaum.

Sluijter, A. M. C. (1995). *Phonetic correlates of stress and accent*. Ph.D. dissertation, University of Leiden.

Suomi, K. (2007). On the tonal and temporal domains of accent in Finnish. *Journal of Phonetics*, *35*, 40–55.

Suomi, K., Toivanen, J., & Ylitalo, R. (2003). Durational and tonal correlates of accent in Finnish. *Journal of Phonetics*, *31*, 113–138.

Turk, A. E. Does prosodic constituency signal relative predictability? A smooth signal redundancy hypothesis. *Laboratory Phonology*, in press.

Turk, A., & Dimitrova, S. (2007). English phrasal stress targets multiple, optional lengthening sites. In *Proceedings of the XVIth international congress of phonetic sciences*, *Saarbruecken* (pp. 1177–1180).

Turk, A. E., & Sawusch, J. R. (1997). The domain of accentual lengthening in American English. *Journal of Phonetics*, *25*, 25–41.

Turk, A. E., & Shattuck-Hufnagel, S. (2000). Word-boundary-related duration patterns in English. *Journal of Phonetics*, *28*, 397–440.

Turk, A. E., & Shattuck-Hufnagel, S. (2007). Multiple targets of phrase-final lengthening in American English words. *Journal of Phonetics*, *35*, 445–472.

Turk, A. E., & White, L. (1999). Structural influences on accentual lengthening in English. *Journal of Phonetics*, *27*, 171–206.

Turk, A., Nakai, S., & Sugahara, M. (2006). Acoustic segment durations in prosodic research: A practical guide. In S. Sudhoff, D. Lenertova, R. Meyer, S. Pappert, P. Augurzky, I. Mleinek, N. Richter, & J. Schliesser (Eds.), *Methods in empirical prosody research* (pp. 1–28). Berlin: de Gruyter.

White, L. (2002). *English speech timing: a domain and locus approach*. Ph.D. dissertation, University of Edinburgh 〈http://www.cstr.ed.ac.uk/projects/eustace/dissertation.html〉.

White, L., & King, S. (2003). The EUSTACE speech corpus 〈http://www.cstr.ed.ac.uk/projects/eustace〉. Centre for Speech Technology Research, University of Edinburgh.

Wightman, C. W., Shattuck-Hufnagel, S., Ostendorf, M., & Price, P. (1992). Segmental durations in the vicinity of prosodic phrase boundaries. *Journal of the Acoustical Society of America*, *91*, 1707–1717.