Available online at www.sciencedirect.com
ScienceDirect
Journal of Phonetics 37 (2009) 145–161
Journal of Phonetics
www.elsevier.com/locate/phonetics

Structural and dialectal effects on pitch peak alignment in two varieties of British English

D.R. Ladd[a,*], Astrid Schepman[b], Laurence White[c], Louise May Quarmby[a], Rebekah Stackhouse[a]

[a]PPLS (Linguistics and English Language), University of Edinburgh, 3 Charles Street, Edinburgh EH8 9AD, UK
[b]Department of Psychology, University of Chester, Parkgate Road, Chester CH1 4BJ, UK
[c]Department of Experimental Psychology, University of Bristol, 12a Priory Road, Bristol BS8 1TU, UK

Received 5 September 2007; received in revised form 28 October 2008; accepted 10 November 2008

Abstract

We report three experiments, based on test sentences read aloud, on the influence of sentence position and phonological vowel length on the alignment of accent-related f_0 peaks in Scottish Standard English (SSE) and Southern British English (RP). One experiment deals with prenuclear accent peaks and the other two with nuclear accent peaks. Three findings confirm reports in the recent literature on several other European languages. First, as has been reported for Dutch [Ladd, D.R., Mennen, I., & Schepman, A. (2000). Phonological conditioning of peak alignment in rising pitch accents in Dutch. *Journal of the Acoustical Society of America*, *107*, 2685–2696], the alignment of prenuclear peaks is later with phonologically short vowels than with long ones, and the effect cannot be explained by actual vowel duration but appears to reflect syllable structure. Second, nuclear peaks are aligned much earlier (relative to the accented vowel) than prenuclear peaks, and, as in Dutch [Schepman, A., Lickley, R., & Ladd, D.R. (2006). Effects of vowel length and 'right context' on the alignment of Dutch nuclear accents. *Journal of Phonetics*, *34*, 1–28], the effect of syllable structure appears to be absent in nuclear accents; instead, their alignment is strongly influenced by whether the accented syllable is in utterance-final position. Third, as in a number of other studies, we find evidence for differences of phonetic detail between languages or language varieties: both nuclear and prenuclear peaks are aligned later in SSE than in RP, and nuclear peaks appear to be aligned earlier in English than in Dutch.

1. Introduction

The past 15 years have seen a great deal of research on the phonetic details of how fundamental frequency (f_0) movements are coordinated in time with the segmental string. Work on a variety of languages has demonstrated the existence of several robust regularities, including *segmental anchoring* and *tonal crowding*. Segmental anchoring is the phenomenon whereby turning points in the f_0 contour (e.g. local maxima and minima) are consistently aligned with identifiable points in the segmental string, such as the beginning of a syllable or the middle of a stressed vowel (e.g. Arvaniti, Ladd, & Mennen, 1998; Ladd & Schepman, 2003; Prieto, van Santen, & Hirschberg, 1995). It appears that f_0 movements do not have specified slope or duration; rather, the time interval between the beginning and the end of an f_0 movement is determined by the duration of the segmental material with which it is associated. Because f_0 movements take time to execute, however, it is possible for the phonology to specify f_0 movements that are 'too close together'. This is tonal crowding. The most obvious examples are provided by prominent pitch accents on adjacent syllables and by f_0 movements immediately following or preceding a phrase break. In such cases, when segmental anchoring requires f_0 movements that are difficult or impossible to produce, we observe systematic adjustments, whereby f_0 turning points are shifted earlier or later, or f_0 movements are truncated or otherwise modified (e.g. Arvaniti, Ladd, & Mennen,

*Corresponding author. Tel.: +44 131 651 3083; fax: +44 131 650 6883.
E-mail addresses: bob.ladd@ed.ac.uk (D.R. Ladd), a.schepman@chester.ac.uk (A. Schepman), laurence.white@bristol.ac.uk (L. White).

0095-4470/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.wocn.2008.11.001

2006; Bruce, 1977, Chapter 5; Grabe, 1998; Lickley, Schepman, & Ladd, 2005; Silverman & Pierrehumbert, 1990).

Work on segmental anchoring has shown clearly that it can be affected by phonological structure. For example, Ishihara (2003) found that the f_0 peak in Japanese words accented on the first mora was reached much earlier in words beginning with CVV or CVN (i.e. with a two-mora syllable) than in words beginning with CVCV (i.e. with a one-mora syllable). In a related finding, Prieto and Torreira (2007) have recently shown that accentual peaks in Spanish are aligned differently depending on whether the accented syllable contains a coda consonant. Prieto and Torreira actually suggest that such structural effects undermine the 'segmental anchoring hypothesis', but as discussed by Ladd (2008, Section 5.1.2), findings such as Prieto and Torreira's still exhibit segmental anchoring in the sense that the slope and duration of an accentual movement are determined by the alignment of the f_0 target points at the beginning and end of the movement. The 'segmental anchoring hypothesis', as the phrase was first used by Ladd, Mennen, and Schepman (2000), was opposed to the 'constant slope' and 'constant duration' hypotheses, and was in no way intended to preclude the relevance of structural factors in determining alignment. In fact, Ladd et al. (2000) showed clearly that phonological factors could be relevant to segmental anchoring: they showed that, in Dutch, there are differences in the alignment of prenuclear accentual peaks depending on whether the vowel of the accented syllable is phonologically long (tense) or short (lax). They suggested that the difference might be attributable to syllable structure, because in general single intervocalic consonants are syllabified with a following onset after long vowels but are ambisyllabic after short vowels (Schiller, Meyer, & Levelt, 1997); that is, they hypothesised that the observed difference between peak alignment with long and short vowels was based on the underlying principle that the peak is anchored in all cases to the end of the accented syllable.

However, it is certainly true that the details of how segmental anchoring is affected by phonological structure are poorly understood. First, as Prieto and Torreira's findings show, it is not clear that the results of Ladd et al. (2000) can actually be explained by assuming that the peak is anchored to the end of the accented syllable. A subsequent study by Schepman, Lickley and Ladd (2006), based on nuclear rather than prenuclear accents, also cast some doubt on that explanation, because it failed to find the expected effect of syllable structure, and instead appeared to show that vowel length affects alignment irrespective of syllable structure. The Schepman et al. study also provided some reason to think that at least in nuclear accents peak alignment might be predicted by some relatively simple proportional measure (e.g. the peak is aligned a fixed proportion of the distance between the onset of the accented vowel and the end of the accented word or phrase). Such proportional characterisations of alignment were suggested by Silverman and Pierrehumbert (1990) and explored by Prieto, van Santen, and Hirschberg (1995); Schepman et al.'s results show that such a model may be possible but that the details are unlikely to be simple. In any case, the Schepman et al. study also raises the more basic question of the difference between nuclear and prenuclear accents. A number of recent reports (e.g. Nibert, 2000 for Spanish, Arvaniti & Baltazani, 2005 for Greek, Schepman et al., 2006 for Dutch) show that the alignment of accentual peaks in nuclear accents is earlier than in otherwise comparable prenuclear accents. One very plausible explanation for this difference is tonal crowding from the upcoming phrase-final boundary tones (Hualde, 2002). However, tonal crowding by itself seems inadequate to account for Schepman et al.'s failure to find an effect of syllable structure in nuclear accents, and other writers (e.g. Face, 2002) have instead proposed that nuclear and prenuclear accents differ in their tonal makeup, not just in whether they are followed by boundary tones. In short, there are a number of conspicuously open questions about the phonological factors that condition the alignment of accentual peaks.

A further issue in connection with segmental anchoring is the apparent fact that many details of f_0/segment alignment are specific to a given language or language variety. Atterer and Ladd (2004) showed that the f_0 rise of prenuclear pitch accents in Standard German is aligned later by Southern speakers than by Northern speakers, and that in both varieties the rise is aligned later than in English. Similar results have been reported for American English by Arvaniti and Garding (2007), who showed that Southern California speakers align certain accent peaks later than Minnesota speakers, and for Irish by Dalton and Ní Chasaide (2007), who showed that three dialects of Irish differ in the way accent peaks are aligned with accented syllables (though they suggest that the alignment differences are accompanied by other differences of detail as well). These findings were clearly foreshadowed in early work of Gösta Bruce (1977, Bruce and Gårding, 1978), who proposed that Stockholm Swedish and Gothenburg Swedish differ precisely in the alignment of what should otherwise be regarded as 'the same' f_0 movements. However, the extent of such cross-language and cross-variety differences, and their phonological interpretation, remains unclear.

The work reported here is intended to shed light on these questions by investigating, for two varieties of English, the effects reported for Dutch by Ladd et al. (2000) and Schepman et al. (2006). Specifically, we tested whether phonological vowel length—which is structurally quite comparable in Dutch and English—has similar effects on peak alignment in the two languages, in both nuclear and prenuclear accents. We also add to the body of evidence on dialect-specific effects on alignment by considering data from both Standard Southern British English (here referred to loosely as 'Received Pronunciation' or RP) and Scottish Standard English (SSE). We included this dimension in the study partly on the basis of informal observations that peak alignment is later in SSE than in RP and partly because the phonological status of vowel length in SSE is problematical.

Scottish Standard English is the name given to the variety of English widely spoken by middle-class speakers in Scotland. It can be distinguished from both Standard Southern British English (RP) on the one hand and 'broad' Scots on the other. Roughly speaking, SSE is standard British English with a Scottish accent, and is distinguished from RP primarily by phonological and phonetic features. Scots diverges from both in quite a number of lexical, grammatical and phonological respects. More detail on the phonology and phonetics of SSE can be found in Giegerich (1992). For our purposes, the main feature of interest is the SSE vowel inventory, which, in comparison with RP, lacks several long–short (tense–lax) contrasts. This is shown in Table 1, in which the vowels are referred to using the names for English lexical sets proposed by Wells (1982). Specifically, there is normally no contrast in SSE between the TRAP set and the BATH sets (so that *Sam* and *psalm* are pronounced identically), between the LOT set and the THOUGHT sets (so that *cot* and *caught* are pronounced identically), or between the FOOT set and the GOOSE set (so that *Luke* and *look* are pronounced identically). In RP the vowels of TRAP, LOT and FOOT are unambiguously short, distinct from the corresponding long vowels of BATH, THOUGHT and GOOSE, respectively. In SSE, where few speakers have such distinctions, it is unclear whether the vowel phonemes that manifest these 'collapsed' length distinctions should count as long or as short, and various phonological criteria provide conflicting evidence. The only unambiguously short vowels in SSE are those of KIT, DRESS and STRUT. Their shortness is attested, as in other varieties of English (and as in German or Dutch, for that matter) by the fact that they cannot occur in stressed monosyllables without a coda: words like /bɪ/, /bɛ/, and /bʌ/ are as ill-formed in SSE as in any other variety of English.

Table 1
RP and SSE vowel inventories.

Typical vowel inventory for RP (ignoring /ɜː/ (NURSE) and ignoring diphthongs except /ɑi/)			
/iː/ (FLEECE)			/uː/ (GOOSE)
	/ɪ/ (KIT)	/ʊ/ (FOOT)	
/eɪ/ (FACE)			/əʊ/ (GOAT)
	/ɛ/ (DRESS)	/ʌ/ (STRUT)	
/ɑː/ (BATH/PALM)			/ɔː/ (THOUGHT)
	/æ/ (TRAP)	/ɒ/ (LOT/CLOTH)	
	/ɑi/ (PRICE)		
Typical vowel inventory for SSE (ignoring diphthongs except /ɑi/)			
/i/ (FLEECE)		/ʉ/ (FOOT, GOOSE)	
/ɪ/ (KIT)		/ʌ/ (STRUT)	
/e/ (FACE)		/o/ (GOAT)	
/ɛ/ (DRESS)		/ɒ/ (LOT/CLOTH, THOUGHT)	
	/ɑ/ (TRAP, BATH/PALM)		
	/ɑi/ (PRICE)		

For more detail see text. The words in small capitals identify the lexical sets of Wells (1982). Throughout the rest of the paper we generally refer to vowels by these keywords except where clarity requires the use of IPA symbols. Where a single vowel phoneme represents more than one lexical set (e.g. LOT/CLOTH), we use only the first mentioned keyword (e.g. LOT).

It should be made clear from the outset that the experiments reported here were originally intended to shed light on the phonological status of vowel length in SSE. In this effort we were unsuccessful, in the sense that we have not provided any better basis for resolving the conflicting criteria for considering the SSE vowels of TRAP/BATH, LOT/THOUGHT and FOOT/GOOSE to be long or short. Certain aspects of the materials and experimental design reflect the original goal of investigating vowel length in SSE, and this—together with the fact that more than 5 years elapsed between the recording of the Experiment 1 data set and the recordings for Experiments 2 and 3—should be kept in mind when reading the results. However, because the KIT/FLEECE and DRESS/FACE pairs appear phonologically comparable in SSE and RP—and phonologically comparable to short/long pairs in German and Dutch—we feel that the results are now worth reporting for what they tell us about the more general questions concerning f_0/segment alignment. We have therefore focused our account on data that are relevant to these questions. In the context of the paper, that is, the main purpose of Experiment 1 is to investigate the effect of phonological vowel length on peak alignment in prenuclear accents in two varieties of English; that of Experiment 2 is to investigate the effect of phonological vowel length on peak alignment in nuclear accents in the same two varieties; and Experiment 3 is intended to replicate Experiment 2 with different materials in order to shed light on two potential methodological problems with the Experiment 2 materials. A very brief digest of our results on SSE vowel length is provided in Appendix 1.

2. Experiment 1: prenuclear accents

Experiment 1 was based on the results for Dutch reported in Ladd et al. (2000) (henceforth LMSch). As noted in the introduction, LMSch found that the alignment of prenuclear accent peaks in Dutch is conditioned by whether the accented vowel is phonologically short or long. Specifically, in Dutch prenuclear rising accents, the f_0 peak is aligned on average somewhat later with short vowels: it tends to be reached near the end of a long vowel, but during the consonant following a short vowel. In keeping with the segmental anchoring hypothesis, however, LMSch were able to show that this effect is not merely due to the duration of the vowel. That is, it is not simply that the f_0 rise takes a fixed amount of time and the peak is therefore reached during the vowel if the vowel's duration is long and after the end of the vowel if the vowel's duration is short. Rather, the difference in peak alignment is still present—though considerably reduced—even when the duration differences are absent. LMSch were able to test this because, in Dutch as in English, duration is not necessarily the primary phonetic correlation of the 'length' distinction, and it is known that the phonologically 'long' high vowels in Dutch (/i, y, u/) are actually quite short in duration (e.g. Nooteboom & Slis, 1972). When they compared accented syllables containing the vowels /i/ and /ɪ/, LMSch found no difference in vowel duration but a significant small difference in alignment.

Experiment 1 looked for an analogous effect in English. Given the structural similarity of vowel length phenomena in Dutch and RP, it seemed reasonable to expect that similar peak alignment effects might be present in English as well. At the same time, given the uncertain status of vowel length in SSE, it also seemed appropriate to compare RP and SSE, both for what it might tell us about the alignment effect and for what it might tell us about the phonology of vowel length in SSE.

2.1. Method

The method we used was essentially identical to that used by Ladd, Mennen, and Schepman for Dutch. Test sentences were prepared containing the vowels of interest in positions where they would normally be pronounced with a rising prenuclear pitch accent. These sentences were then read aloud under laboratory conditions by volunteer speakers of both RP and SSE. We have shown elsewhere (Lickley et al., 2005) that this general approach is a valid way of studying the phonetic detail of intonation; specifically, we have found that conclusions based on prepared sentences read aloud match those based on utterances produced in unscripted task-oriented dialogues.

2.1.1. Materials

For each of the four English vowels under consideration (FLEECE, KIT, FACE, DRESS) we constructed 16 or 17 test sentences (66 in total). In all cases, the test vowel was the lexically stressed vowel of the word that was expected to bear the first major pitch accent of the sentence when read aloud, and in all cases it was followed by at least one (in most cases two or three) unstressed syllables in the same word. The test words were placed in phrases that were likely to be read as closely knit prosodic units with two pitch accents (the prenuclear test accent and a following accent), and these phrases were themselves followed by at least a further phrase containing at least one more accentable word. All of these conditions were intended to ensure that the peak of the pitch accent on the test vowel was not nuclear in its phrase and was not subject to any sort of tonal crowding from the following context. In addition, the test vowel was followed wherever possible by a nasal consonant in order to make it easy to identify the f_0 peak and the segment boundaries. Where enough words with nasals could not be found, we completed the materials with words in which the test vowel was followed by /l/ or a voiced fricative instead.

Example sentences include the following (the test word is in italics and the test syllable is in boldface):

It was a ***seem****ingly* endless meeting. (FLEECE)
He had a ***lim****ited* grasp of the subject. (KIT)
There were *at****tain****able* targets for inflation. (FACE)
There was a ***men****acing* storm in the mountains. (DRESS)

The full set of test words for each vowel is given in Appendix 2. In addition to the test sentences, there were 130 fillers.

2.1.2. Speakers

The materials were recorded by five native speakers of RP and five of SSE. Data from two speakers (one from each dialect) were excluded from the final analysis: one (English) who turned out to be a non-native speaker with a detectable non-English accent, and one (Scottish) who made a large number of reading errors and had very little f_0 variation. The speakers used were three Scottish females and one Scottish male and two English females and two English males. All speakers were students at the University of Edinburgh.

2.1.3. Procedure

The recordings were made on professional equipment in the recording studio of the phonetics laboratory at the University of Edinburgh. Speakers were presented with one sentence at a time on a computer screen, and pressed a key to advance to the next sentence. The recording session started with a set of 178 sentences for a different experiment (reported in Ladd & Schepman, 2003), followed by a break, followed by the 196 sentences relevant to the current experiment (66 experimental and 130 filler sentences). The fillers were interspersed pseudo-randomly among the experimental items, with the constraint that there were 10 fillers at the start of the list, and 5 at the end. No instructions concerning intonation were given; speakers were only asked to read the sentences in a relaxed and natural way. They were asked to repeat the entire sentence if they detected that they had made an error or if they felt their reading was disfluent or not as intended. The recordings were made on DAT and transferred to disk, digitised at a sampling frequency of 16 kHz. f_0 was extracted using the *get-f_0* algorithm of the *xwaves* signal-processing package, using its default settings, i.e., a 7.5 ms correlation window and a 10 ms frame shift.

Acoustic measurements were made by hand on the basis of simultaneous screen displays of f_0 contour, spectrogram and waveform, using standard criteria for segmentation (e.g. Peterson & Lehiste, 1960): vowel–consonant boundaries were located at breaks in the formant structure (generally with a corresponding drop in waveform amplitude), while consonant–vowel boundaries were located at the onset of regular vocalic formant structure, using the amplitude and shape of successive pitch periods as a subsidiary guide. The measurements were made by author

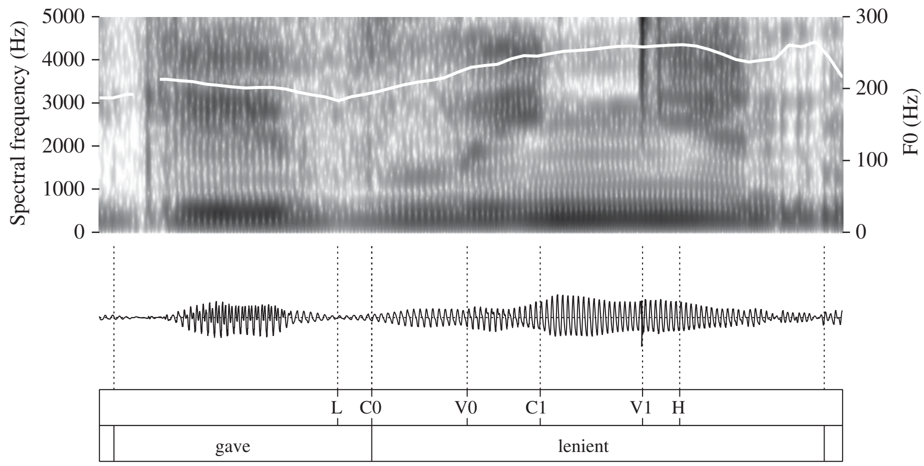

Fig. 1. Illustration of how the f_0 targets L and H and the segmental landmarks in the vicinity of the accented syllable were marked in Experiment 1. For clarity the figure focuses on the relevant portion of the utterance; the full text is *He gave lenient marks to his favourite students.*

LMQ under the supervision of AS. The following segmental landmarks were identified for each test utterance.

- C0: The start of the syllable–initial consonant. (Note that some target words had no such consonant.)
- V0: The start of the vowel in the target syllable.
- C1: The offset of the vowel and start of the final consonant of the target syllable.
- V1: The start of the vowel in the syllable following the target syllable.

In addition, the following f_0 landmarks were identified:

- H: The f_0 peak on or closest to the target syllable.
- L: The f_0 valley preceding H (see further Section 2.2.4 below).

The f_0 peak was identified by eye as the highest extracted frame value in the rising–falling pitch accent contour accompanying the test vowel. In most cases it was easy to identify a single frame as the peak. However, on the rare occasions in which two or more frames had identical f_0 values, we consistently chose the earliest as the designated H. If the pitch contour was clearly broken up by consonant perturbation, we did not make a measurement for H, but retained the segmental values for duration analysis.

We had not initially planned to measure the valley at the onset of the target syllable (L), because it would have meant designing materials in which the stressed vowel was both followed and preceded by a sonorant to make reliable f_0 extraction possible. (As noted earlier, it was sometimes difficult to find enough test words in which the following consonant was a sonorant.) However, in a second round of measurements we did measure L wherever possible, to examine a subsidiary hypothesis discussed below. L was identified as the frame with the lowest f_0 value at the beginning of the accentual rise. Wherever it appeared that the 'true' L was masked by voicelessness and/or obstruent perturbations, we did not record a value and treated the measurement as missing.

A typical utterance with the acoustic landmarks indicated is shown in Fig. 1.

From the measurements just described we derived the two variables reported here, VDur (duration of the stressed vowel, i.e. the interval between V0 and C1) and PA-Off (alignment of the f_0 peak relative to the offset of the stressed vowel, i.e. the interval between C1 and H; this variable takes negative values when H precedes C1 and positive values when H follows C1).

2.2. Results and discussion

Out of 528 potential utterances (66 sentences $\times$ 2 dialects $\times$ 4 speakers), we obtained usable segmental measurements from 509, and usable measurements of H from 442. Missing segmental data consisted primarily of pronunciation errors (e.g. misread words, speech errors), while missing H data were primarily due to unusable contours (e.g. pitch extraction problems, unexpected accent patterns).

Results (means for VDur and PA-Off) are shown in Fig. 2. It can be seen impressionistically that PA-Off is different for the 'long' vowels of FLEECE and FACE than for the 'short' vowels of KIT and DRESS, *in both RP and SSE*. It can also be seen that the duration differences between the long and short vowels are much smaller in SSE, and that overall alignment is later in SSE than in RP. Our main analysis was intended to put these impressionistic findings on a secure footing.

2.2.1. Main analysis

We ran separate analyses for the dependent variables PA-Off and VDur, using a 2×2 by-items ANOVA, with

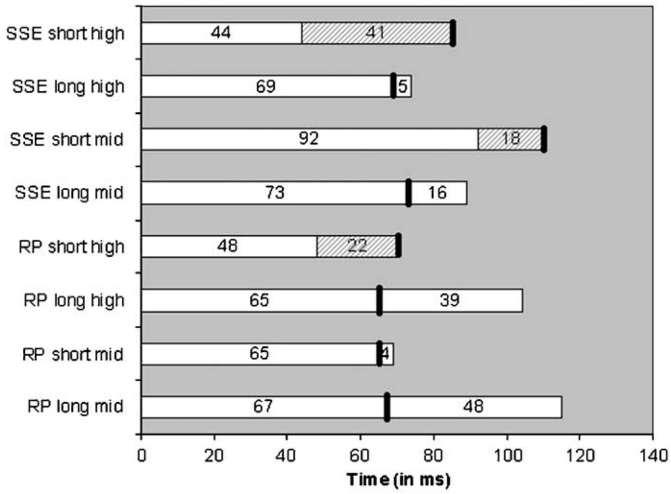

Fig. 2. Means for Experiment 1. The white bars represent vowel duration, and the heavy vertical lines across the bars represent the location of H (the accentual f_0 peak). The numbers in portions of the bars represent the duration of the relevant intervals in ms. In three cases, H aligned after the end of the vowel. In these cases the consonantal duration between the end of the vowel and the location of H is shown by a shaded bar. Here, too, the duration of this post-vocalic interval in ms is shown by the number in the shaded part of the bar. RP = Received Pronunciation (English), SSE = Scottish Standard English; long and short refer to phonological vowel length, while high and mid refer to phonological vowel height.

vowel length (short vs. long) and dialect (RP vs. SSE) as the independent variables and with items (utterances) as the sampling factor. Only PA-Off, of course, is directly relevant to our attempt to investigate for English the finding by Ladd et al. (2000) on Dutch, but the VDur results are useful in helping us to understand the general pattern of results.

For PA-Off, we found the main effect of vowel length that we had expected ($F(1,438) = 121.54$, $p<0.001$), analogous to LMSch's finding for Dutch: peaks were aligned earlier with long vowels (on average 27 ms *before* C1) than with short vowels (on average 19 ms *after* C1). We also found a main effect of dialect ($F(1,438) = 41.65$, $p<0.001$), with alignment generally later in SSE than in RP. There was no significant interaction between these two independent variables ($F<1$).

For VDur, both main effects and the interaction were significant ($F(1,505) = 20.44$, $p<0.001$ for dialect, and $F(1,505) = 251.63$, $p<0.001$ for vowel length). The key effect was that, unsurprisingly, phonologically long vowels were of greater duration than phonologically short ones (long: 96 ms; short: 63 ms). There was an interaction between vowel length and dialect, which was due to the fact that the duration of long and short vowels differed more in RP (long: 109 ms; short: 57 ms) than in SSE (long: 81 ms; short: 67 ms). Note, though, that in both dialects the main effect of vowel length was significant ($p<0.001$).

In addition to the analysis just summarised, we carried out several supplementary analyses, reported in the following paragraphs.

2.2.2. Vowel height differences

In the main analysis we did not consider the difference in vowel height between FLEECE/KIT and FACE/DRESS. However, an inspection of the means shows differences between the mid and high vowels that called for further examination. We therefore re-ran the analysis just reported with vowel height added as a factor. This revealed that there was a significant effect of vowel height on both measures. As might be expected, VDur was substantially longer for mid vowels than for high vowels (mid: 91 ms; high: 67 ms; $F(1,501) = 213.66$, $p<0.001$); additionally, PA-Off was slightly later for high than for mid vowels (high: 4 ms after C1; mid: 12 ms before C1; $F(1,434) = 16.96$, $p<0.001$). There were also significant two- and three-way interactions between vowel height and the other factors for VDur, but no significant interactions for PA-Off. These patterns do not appear to affect our basic conclusions, because they appear to result from intrinsic vowel duration differences and from the fact that the duration difference in FLEECE/KIT is greater than in FACE/DRESS.

Subsequent 2×2 ANOVAs run on the high and mid vowels separately revealed that in SSE we have a situation that is precisely like the case of Dutch /i/ and /ɪ/ discussed by LMSch: the mid vowels of FACE and DRESS were virtually identical in duration (FACE: 89 ms; DRESS 92 ms; $F<1$) but differed substantially in alignment (FACE 15 ms before C1; DRESS 18 ms after C1; $F(1,110) = 20.69$, $p<0.001$). For informal comparison, LMSch reported durations of 65 and 63 ms, respectively for Dutch /i/ and /ɪ/, and peak alignment values of 21 and 32 ms after C1, respectively. This makes it very clear that, as in Dutch, the difference in alignment cannot be attributed to differences in vowel duration, and that some phonological factor must be responsible.

2.2.3. Follow-up experiment on SSE

The pattern of results just reported for SSE was replicated in a subsequent experiment using only SSE speakers. Because of the clear effect of vowel length on alignment, we thought that alignment measures might be used as a criterion for deciding whether the other vowels of SSE are to be considered long or short. We therefore extended the materials from Experiment 1 to include comparable sentences for the other stressed vowel phonemes of SSE, and established alignment and duration data for all SSE vowels. The results clearly replicated the findings just reported for FLEECE, KIT, FACE and DRESS, but were inconclusive in relation to the larger question of vowel length in SSE. As noted in the introduction, we then abandoned this line of investigation and do not report the detailed results here (but see Appendix 1); we mention the follow-up study to make clear that the effects reported here are reliable and robust.

2.2.4. Dialect differences and alignment of valley

As reported above, there was a clear main effect of dialect on PA-Off: H peaks in SSE were aligned on average

27 ms later than in RP (SSE: 8 ms after C1; RP: 19 ms before C1). This led us to wonder whether the effect is limited to the peak (i.e. whether the onset of the accentual rise is anchored at the start of the syllable in both dialects and the rise is correspondingly longer in SSE; cf. Dilley, Ladd, & Schepman, 2005), or whether in SSE both the beginning and the end of the accentual rise are later than in RP (as in Southern and Northern varieties of German, Atterer & Ladd, 2004). As noted above, our materials were not specifically designed for locating the f_0 minimum at the beginning of the rise, but on a second pass through the speech files we were able to mark the f_0 minimum (L) in 133 cases. We then computed the temporal interval between L and C0 (the beginning of the onset consonant), and analysed the data with a $2 \times 2 \times 2$ ANOVA (with independent variables vowel length, vowel height and dialect). This showed that there was a small numerical difference between the dialects (RP speakers aligning 1 ms after the consonant onset and SSE speakers 6 ms after the consonant onset). This difference is in the same direction as the difference in peak alignment, but was not statistically significant ($F<1$). None of the other effects or interactions in this analysis reached significance.

2.2.5. Speaker differences

Because of the relatively small number of speakers, we checked for speaker effects by re-analysing the data for the two dialects separately in two 2×4 ANOVAs (vowel length $\times$ speaker). There were main effects for speaker in each dialect for both VDur: $F(3,251) = 6.54$ for RP, and $F(3,242) = 7.75$ for SSE; and for PA-Off: $F(3,216) = 11.85$ for RP, and $F(3,210) = 12.21$ for SSE, all $p<0.001$. Importantly, however—with one exception—there was no interaction between speaker and vowel length. (The one exception was an interaction between speaker and length in RP for VDur ($F(3,210) = 2.89$, $p<0.05$), which was due to one speaker who showed a greater difference in duration between long and short vowels than the other RP speakers in the sample.) None of the alignment patterns showed significant interactions between speaker and vowel length. This general pattern of individual differences—differences in absolute alignment and duration values, but little or no difference in the effects of the experimental manipulations—has been observed in our work before (Schepman et al., 2006; Lickley et al., 2005).

2.2.6. Summary

The key findings of Experiment 1 can be summarised as follows. First—and rather straightforwardly—there is a significant effect of the difference between SSE and RP: f_0 peaks in SSE are consistently later than those in RP. The average difference is on the order of 30–50 ms. This difference in peak alignment may be accompanied by a smaller difference in the alignment of the f_0 minimum at the beginning of the accentual rise, but a very large sample would be needed to establish that; in our results the numerical difference between the means of the f_0 minima is not statistically significant. Either way, these findings add to the evidence that fine differences of alignment are among the phonetic differences we may find between one language and another or between different varieties of the same language, but otherwise shed little light on what controls segmental anchoring in the first place.

Second and more importantly, English shows a distinction between long vowels and short vowels in the way the f_0 peak of a prenuclear rising accent is aligned with the accented syllable. This is exactly comparable to the distinction found for Dutch by Ladd et al. (2000). On average, the peak is aligned during the accented vowel if the vowel is long and during the following consonant if the vowel is short. As in Dutch, it appears that the effect of vowel length on alignment is due in some way to phonological or structural factors, not merely to durational differences in the vowels. This can be seen most clearly in SSE, where the vowels of FACE ('long') and DRESS ('short') do not differ in duration, but still exhibit the difference in alignment, exactly as shown by LMSch for the Dutch /i–ɪ/ pair.[1]

As suggested in the introduction, the nature of the phonological or structural factors responsible for the influence of vowel length on alignment is not immediately clear, but the most obvious explanation would appear to involve syllable structure. There are at least two versions of this explanation, one based on syllable boundaries and one based more generally on the syllable's weight and/or segmental makeup. In the boundary-based version, which was LMSch's original proposal, the alignment of the peak is based on the location of the syllable boundary; this requires us to acknowledge that the intervocalic consonants following the short vowels are ambisyllabic. Specifically, in our materials, as in LMSch's Dutch materials, the long-vowel cases unambiguously involve open syllables (e.g. *see.ming.ly, a.ttai.na.ble*), while the short-vowel cases arguably involve checked syllables, with the following intervocalic consonant treated as ambisyllabic (e.g. *li[**m.m**]i.ted, me[**n.n**]a.cing*). The problem with this account is that there is no objective way of locating the syllable boundary within a supposedly ambisyllabic consonant, making the hypothesis difficult to test. In the alternative version of the syllable-structure explanation, based on the syllable's segmental makeup or weight, we

[1]Although the case of the SSE mid vowels seems to represent compelling evidence for structural factors in segmental anchoring, it is important to note for the sake of completeness that the RP data are actually also consistent with the constant-duration hypothesis, i.e. against any notion of segmental anchoring whatsoever. As can be seen from informal inspection of Fig. 2, the alignment of the prenuclear peak in RP is uniformly between 65 and 70 ms after the onset of the vowel. Given the weight of evidence in favour of some form of segmental anchoring in several languages—including, of course, the matched SSE data—we are not seriously calling the segmental anchoring hypothesis into question, but it is certainly true that for this particular set of data from one variety of English the constant-duration hypothesis offers a simpler account. Further research seems certain to reveal further surprises on our way to understanding how f_0/segment alignment really works.

could divide the word into conventional syllables without allowing ambisyllabic consonants, and simply note that the long-vowel syllables are heavy (i.e. consist of two moras) while the short-vowel syllables are light (i.e. consist of only one). In this version, which is easier to reconcile with the findings of Prieto and Torreira (2007) discussed in the introduction, the alignment of the peak is somehow constrained to be later than the end of the first mora. In the absence of a detailed quantitative model, this explanation is not very easy to test either; Prieto and Torreira suggest that the difference between light and heavy (or open and closed) syllables depends in some way on the coordination of laryngeal and supralaryngeal gestures in speech production, noting that such an explanation assumes that the syllable and the prosodic word function as potentially interacting domains of articulatory gestures.

Our results provide little basis for distinguishing between a boundary-based and a weight-based account of the effect of syllable structure on alignment, partly because neither account can be precisely formulated given our current understanding, though there may be a slight preference for the weight-based version. The boundary-based version is conspicuously difficult to reconcile with the RP long-vowel data, where the peaks are aligned well before the end of the syllable. But neither version is immediately convincing, and for that matter, it is not possible to rule out an alternative view that in some way the alignment patterns depend directly on the phonological length of the vowel itself rather than on syllable structure. This of course is what Schepman et al. (2006) suggested on the basis of their results with Dutch nuclear accents, because with nuclear accents syllable structure was clearly irrelevant. With this in mind we now consider the alignment of accent peaks with nuclear accents in English.

3. Experiment 2: nuclear accents (1)

As discussed in the introduction, Schepman et al. (2006) extended the Dutch findings of Ladd et al. (2000) to nuclear accents. They found that the effect of phonological vowel length on peak alignment is present in nuclear accents as well as in prenuclear accents, but that in the nuclear context it cannot be attributed to syllable structure. Since, as we just saw, the explanation for the vowel length effect in prenuclear accents is no clearer in English than in Dutch, we ran two additional experiments on English to see if the difference between nuclear and prenuclear accents found for Dutch would be found in English as well. We also once again included speakers of SSE and RP, in order to see whether the dialect difference discovered in Experiment 1 for prenuclear accents would extend to nuclear accents as well.

3.1. Method

The general method was very similar to that in Experiment 1. We prepared short sentences containing the test words and recorded speakers reading these sentences aloud under laboratory conditions. Measurements were made using *xwaves* screen displays in exactly the same way as before. (This time the measurements were made by author RS, under the supervision of DRL.) The following paragraphs report only the ways in which the procedures in Experiment 2 differed from Experiment 1.

3.1.1. Materials

We constructed at least 18 test sentences for each of the four vowels under investigation. In all cases, the test vowel was the lexically stressed vowel of the test word, and the test word was in sentence-final position and intended to bear the nuclear accent of the sentence. For each vowel, approximately half of the test words had stress on the final syllable and the other half on the penultimate syllable. (Most of the test words with 'final stress' were actually monosyllables, but also included a few words like *unreal*; most of those with 'penultimate stress' were disyllables, but also included a few words like *remaining*.) The test vowel was always preceded and followed by a sonorant in order to make it possible to get reliable measurements of both the f_0 peak and the preceding f_0 valley. To the greatest extent possible we used nasals for both flanking consonants, e.g. *men*, *name*, *mean*, *maimed*, *anaemic*, *minnow*, *memo*. Where this was not possible we used words in which the test vowel was preceded by /l/ or /r/ (or in one case /w/) and/or followed by /l/—words such as *kneel*, *ring*, *Nell*, *leaning*, *limit*, *railing*, *melon*.

A full list of the test words for each vowel is given in Appendix 3. A few of the words were used in more than one test sentence. In total there were 74 test sentences. Most of the test sentences were very short and were expected to have only two accents, e.g.

The dog's name was Millie.
I was speaking with Len.
He was squeezing a lemon.
She gave me the ring.

3.1.2. Speakers

The materials analysed were recorded by three native speakers of RP and three of SSE. The SSE speakers were students or staff at the University of Abertay Dundee and the RP speakers were students at the University of Edinburgh. Recordings were made of a few other speakers in addition to these six but these recordings were not analysed because of very monotone or disfluent reading (or, in the case of one of the SSE speakers, because her accent was judged to be rather anglicised).

3.1.3. Procedure

The recordings of the RP speakers were made in the phonetics laboratory at the University of Edinburgh. The procedures were the same as in Experiment 1, except that as a result of studio upgrades in the intervening years the

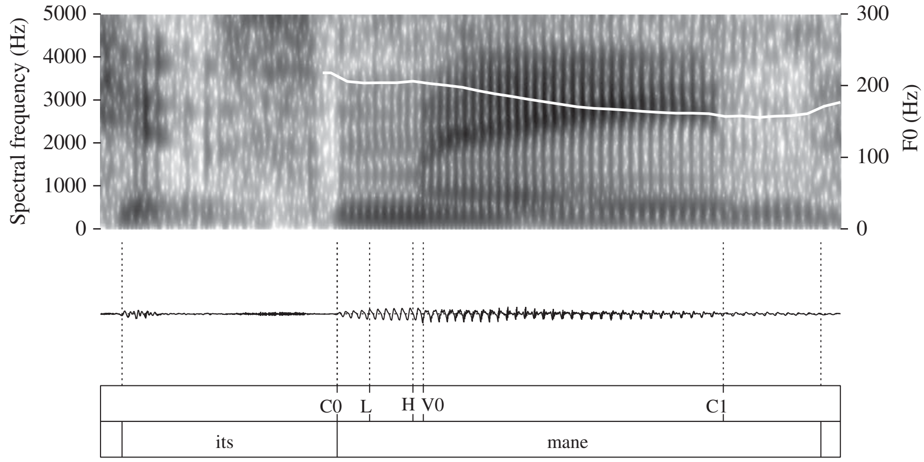

Fig. 3. Illustration of a typical nuclear accent contour in Experiment 2, with f_0 and segmental landmarks indicated, showing the difficulty of identifying a pitch peak (H). The overlapping labels are left-to-right, 'H' and 'V0'. For clarity the figure focuses on the relevant portion of the utterance; the full text is *The horse shook its mane.*

recordings were made direct to disk. The SSE speakers were recorded in a quiet room at the Division of Psychology at the University of Abertay Dundee on a DAT recorder using a professional microphone. As in Experiment 1, no specific instructions concerning intonation were given; speakers were only asked to read the sentences in a relaxed and natural way. However, because the sentences were so short, speakers were told explicitly to read each sentence separately and not to read the sentences like items in a list. This was to avoid having the speakers fall into a listing intonation with a rise in pitch at the end of each sentence. Sentences were presented on A4 paper, with 20 sentences per page. In addition to the 74 test sentences, there were 304 fillers.[2] The first 35 and last 20 sentences were fillers, but otherwise fillers and test sentences were randomly interleaved. The recordings yielded 373 usable test sentences in total for the six speakers.

Measurement techniques were identical to those used in Experiment 1. However, we quickly discovered that the accentual peak in these nuclear accents is aligned very close to the beginning of the stressed vowel, which meant that the PA-Off variable used in Experiment 1 was not well suited to examining our hypotheses. If the peak is aligned close to the onset of the vowel, a measure of alignment based on the difference between the peak and the *offset* of the vowel will almost by necessity show an effect of vowel length on alignment wherever there is also an effect of vowel length on VDur. For Experiment 2, we therefore report two derived variables related to alignment rather than just one. Specifically, we measured both the distance between the vowel onset and the peak (PA-On) and the distance between the peak and the vowel offset (PA-Off).

3.2. Results and discussion

The most noteworthy feature of many of the utterances was that the nuclear accent peak was not very prominent for most of the speakers. A typical example is shown in Fig. 3. Because of this, it was difficult to be confident that the peak data were very reliable or even very meaningful, and we considered abandoning the data set altogether. Nevertheless, we did proceed with the analysis, using the measurement procedures applied in Experiment 1 and locating the highest extracted f_0 value in the vicinity of the accented vowel. Subsequent comparison with the data from Experiment 3 (which were based on more prominent nuclear accent peaks) suggests that our concerns about reliability were largely unwarranted and that the following three broad conclusions can be drawn. First, there was a large difference in alignment between the nuclear accents of Experiment 2 and the prenuclear accents of Experiment 1. In addition, there was probably an effect of vowel length on alignment of nuclear peaks like that for prenuclear peaks, but it is difficult to be confident of this conclusion. Second, as with prenuclear accents, nuclear accent peaks in SSE were aligned later than in RP. Third, there was a clear difference in alignment between final-stress and penultimate-stress words. In the following paragraphs we report these findings in more detail.

The analysis consisted of three $2 \times 2 \times 2$ ANOVAs, one for each of the three dependent variables VDur, PA-On and PA-Off. The independent variables were phonological vowel length (short vs. long), stress position (final stress vs. penultimate stress) and dialect (RP vs. SSE). Again, the sampling factor was items. Means for these analyses are shown in Fig. 4. As in Experiment 1, we carried out a check for effects of speaker, which led to similar conclusions to

[2]Because our original aim was to shed light on phonological vowel length in SSE, the recorded data set actually included instances of ten stressed vowel phonemes of SSE. However, we treat all but the FLEECE/KIT and FACE/DRESS pairs as fillers and report only the data for those two pairs; this explains the large proportion of fillers in our materials.

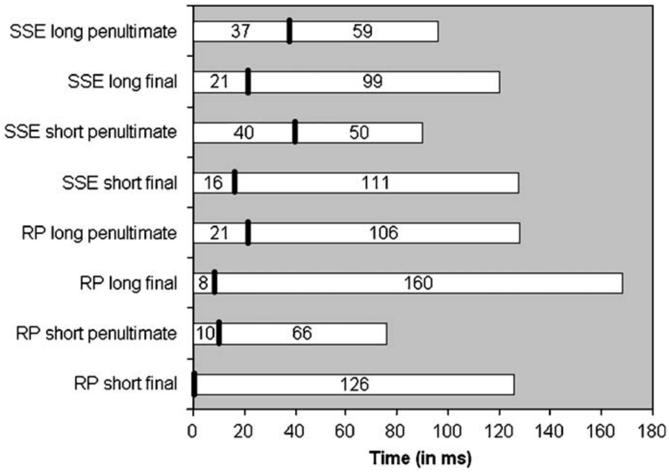

Fig. 4. Means for Experiment 2. The white bars represent vowel duration, and the heavy vertical lines across the bars represent the location of H (the accentual f_0 peak). The numbers in portions of the bars represent the duration of the relevant intervals in ms; the number to the left of the heavy vertical line corresponds to PA-On and that to the right to PA-Off. Note that for RP 'short final' case, peak alignment is at the vowel onset, and so the heavy vertical line coincides with the vertical axis. RP = Received Pronunciation (English), SSE = Scottish Standard English; long and short refer to phonological vowel length, while final and penultimate refer to the position of the stressed syllable in the sentence-final target word.

those described in Section 2.2.5: there were some individual differences, but the crucial effects generalised to all speakers.

3.2.1. Comparison of nuclear and prenuclear accent peaks and effect of vowel length

Inspection of the means from Experiments 1 and 2 suggests that the nuclear accent peaks are aligned much earlier than the prenuclear peaks reported in Section 2.2. The nuclear peaks are aligned on average 19 ms after the vowel onset or 97 ms before the vowel offset, compared to 75 ms after vowel onset or 6 ms before vowel offset in our prenuclear data set. As noted in the introduction, such alignment differences between nuclear and prenuclear accents have been found in several other European languages, including American English (Steele, 1986), Spanish (Nibert, 2000; Prieto, van Santen, & Hirschberg, 1995), Greek (Arvaniti & Baltazani, 2005) and Dutch (Schepman et al., 2006). Note also that our values for English nuclear alignment are considerably earlier in the vowel than the values observed by Schepman et al. for Dutch nuclear accents: 19 ms after vowel onset or 97 ms before vowel offset, as against 75 ms after vowel onset or 36 ms before vowel offset for Dutch. Strictly speaking both of these findings are based on informal comparisons across experiments rather than formal statistical tests, but given the shared methodological approach and the size of the differences we are probably justified in taking these findings seriously.

There were significant effects of phonological vowel length on VDur and on PA-Off (for both, $F(1,365) > 14.87$, $p<0.001$). Long vowels were of greater duration than short vowels, and PA-Off was 'earlier' (i.e. further from the offset of the vowel) when vowels were long. However, the effect of vowel length on PA-On was not significant. Taken at face value, this combination of findings could mean that the true basis of alignment in nuclear accents is simply that the peak occurs a fixed distance from the beginning of the vowel, irrespective of phonological vowel length (the main effect for PA-Off is then a mathematically inevitable consequence of the greater duration of phonologically long vowels). Alternatively, it may be that there is an effect of phonological vowel length on PA-On in addition to the effect on PA-Off, but that it is difficult to detect statistically because nuclear peaks are aligned so close to the onset of the accented vowel.

There were also two sets of significant interactions. First, dialect interacted significantly with vowel length for both VDur and PA-Off (both $F(1,365) > 16.97$, $p<0.001$). The explanation for this appears to be that in RP, long and short vowels differ greatly in duration ($F(1,182) = 64.56$, $p<0.001$), while in SSE they do not ($F<1$). There were corresponding differences in PA-Off, such that RP showed a large and significant difference between long and short vowels ($F(1,182) = 27.39$, $p<0.001$), but SSE did not ($F<1$). (Note that this provides additional support for the idea that effects of vowel length on PA-Off are artefacts due to differences in vowel duration.) Second, dialect interacted significantly with stress position for VDur ($F(1,357) = 7.14$, $p<0.01$): the vowel duration difference between SSE and RP was more pronounced when stress was final (RP: 147 ms; SSE: 123 ms), than when stress was penultimate (RP: 101 ms; SSE: 93 ms). This seems to indicate that RP exhibits greater utterance-final lengthening than SSE, though other explanations are also possible.

3.2.2. Comparison of SSE and RP

As with prenuclear accents, we found that nuclear accent peaks in SSE were aligned later than in RP. This can be seen in Fig. 4. The difference was smaller than the difference with prenuclear accents, but it was statistically significant regardless of which measure of alignment was chosen (PA-On: RP, 10 ms after vowel onset; SSE, 29 ms after vowel onset; $F(1,365) = 26.27$, $p<0.001$); PA-Off: RP, 120 ms before vowel offset; SSE, 85 ms before vowel offset; $F(1,365) = 68.05$, $p<0.001$). Dialect also had a significant effect on vowel duration ($F(1,365) = 25.90$, $p<0.001$): RP vowels were longer (mean 124 ms) than SSE vowels (mean 108 ms).

3.2.3. Comparison of final-stress and penultimate-stress words

There was a clear difference in alignment between final-stress and penultimate-stress words. Target vowels in words with final stress were considerably longer than in those with penultimate stress (final: 135 ms; penultimate: 97 ms; $F(1,365) = 145.82$, $p<0.001$); there was no significant interaction with vowel length ($F(1, 365) = 3.40$, n.s.). The difference in duration can presumably be attributed to phrase-final lengthening (e.g. Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992) and to the greater accentual lengthening of stressed syllables in monosyllables than in disyllables (e.g. Turk & White, 1999). At the same time, even though the vowel was longer in final-stress words, peak alignment in final-stress words was *earlier*, regardless of which measure is used to characterise alignment quantitatively (PA-On: final, 11 ms after vowel onset; penultimate, 27 ms after vowel onset; $F(1, 365) = 18.83$, $p<0.001$; PA-Off: final, 124 ms before vowel offset; penultimate, 70 ms before vowel onset; $F(1, 365) = 163.53$, $p<0.001$). That is, both duration and alignment are sensitive to the variables we have manipulated: vowels in final-stress words were longer than in penultimate-stress words, but alignment in final-stress words was consistently earlier by both measures. This finding is consistent with the idea that peak alignment in nuclear accents is affected by time pressure or 'tonal crowding': the peak must occur earlier in final syllables in order to make room for the phrase-final fall in pitch occurring on the same syllable, whereas in penultimate-stress words the final pitch fall occurs on the syllable following the accented syllable. (Comparable findings for Greek are reported by Arvaniti et al., 2006.)

3.2.4. Summary

By and large, the findings of Experiment 2 replicate relevant findings from other recent work. First, nuclear accent peaks are aligned earlier in RP than in SSE, and (making due allowance for the difficulty of comparing across studies) they also appear to be aligned earlier in English than in Dutch. This adds to the growing body of evidence that peak alignment is a phonetic parameter on which languages and language varieties can differ. Second, comparison of the means from Experiments 1 and 2 suggests that nuclear accent peaks in English are aligned considerably earlier than prenuclear accent peaks; this too has been reported for several other European languages, including Dutch, Spanish and Italian. However, our data provide no further insight into why this might be so, though they are certainly compatible with the time pressure or 'tonal crowding' hypothesis of Hualde and others mentioned in the Introduction.

Third, and arguably more relevant for our understanding of the factors that condition alignment, Experiment 2 provides no unambiguous evidence that peak alignment in nuclear accents is affected by phonological vowel length. Specifically, the differences that emerge from the statistical analysis in Experiment 2 could be taken as evidence that nuclear peaks are aligned a fixed distance from the vowel onset, irrespective of phonological vowel length, and that apparent effects of vowel length are artefacts of defining alignment relative to the offset of the accented vowel. This runs counter to the main conclusion of Schepman et al. (2006), who stated that they had found a direct effect of vowel length on alignment of peaks with nuclear accents in Dutch. However, our finding for nuclear accents in English may favour the alternative possible explanation offered by Schepman et al. for Dutch, namely that alignment of nuclear peaks is *proportionally* invariant, relative to the duration of the word, the foot, or some other such phonological domain. The possibility of some kind of proportional invariance is bolstered by the finding that nuclear accents show a clear difference in alignment between sentence-final syllables and sentence-penultimate syllables, coupled with a clear difference in vowel duration. This favours an explanation in terms of proportional invariance because the duration and alignment effects seem to go in opposite directions: the vowels of final accented syllables are substantially longer than the vowels of penultimate accented syllables, yet accent peaks are aligned 'earlier' (by both measures) with final syllables than with penultimate syllables. This makes it impossible to relate alignment to the duration of either the accented vowel or the accented syllable, but is roughly what we would expect if the peak alignment is proportional to the duration of the accented word (or alternatively, if it is proportional to the duration of the accented vowel plus any following segments in the accented word).

4. Experiment 3: nuclear accents (2)

In part because of the extremely flat accent 'peaks' we found in Experiment 2, we initially had little confidence in our findings from that experiment and wanted to discover some way of inducing speakers to produce more salient peaks on their nuclear accents without instructing them explicitly to do so. The method we used for this purpose was to produce new materials in which the nuclear accent on the test word was not expected to be preceded by a prominent prenuclear accent. We reused most of the monosyllabic test words from Experiment 2 but shortened the sentences considerably. For example, we replaced *Two of the Spice Girls are called Mel* with *He likes Mel* and *He was reading her mail* with *He read his mail.* This manipulation 'worked', in the sense that the accent peaks were indeed easier to identify with confidence (see Fig. 5 below).

A more substantive reason for wanting to re-run Experiment 2 is the fact that the nuclear accent peaks we found in English were aligned very much earlier than those in the Dutch data reported by Schepman et al. (2006). We thought it possible that this was due not to any difference between Dutch and English, but rather to the fact that in the English data the nuclear-accented words were in absolute utterance-final position, whereas in the Dutch materials they were followed by a post-nuclear content word (usually a non-finite verb form). For example, most of the Dutch sentences were of a form similar to *Hij heeft de maan gezien* (lit. 'He has the moon seen'), with the nuclear accent on *maan*. Such sentences can easily be constructed in Dutch, but in English the only words that regularly and predictably occur in post-nuclear position

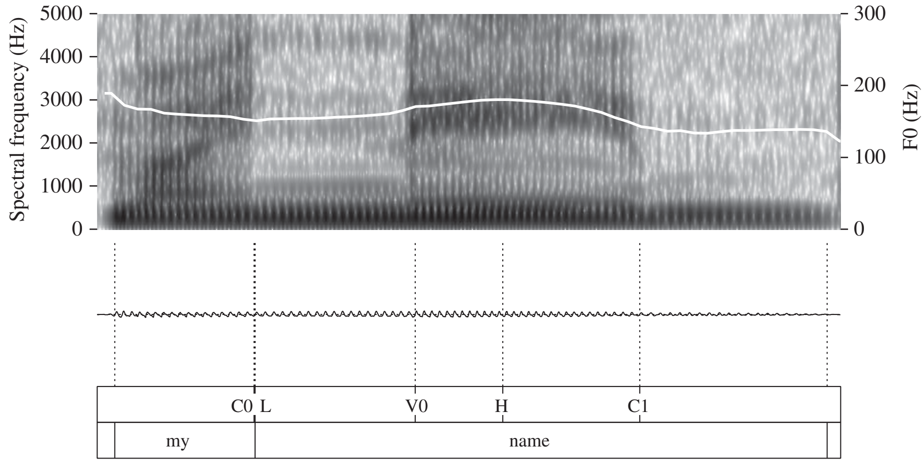

Fig. 5. Illustration of a typical nuclear accent contour in Experiment 3, with f_0 and segmental landmarks indicated. Comparison with Fig. 3 shows how the pitch peaks (H) were generally easier to locate in Experiment 3 than in Experiment 2. The labels 'L' and 'C0' coincide. For clarity the figure focuses on the relevant portion of the utterance; the full text is *That's my name.*

(again, without giving the speakers explicit instructions on where to place the accent) are adverbs like *now*, *again*, and the like. We therefore constructed a second set of sentences for Experiment 3, using the same monosyllabic test words, in which the nuclear-accented test word was followed by a post-nuclear adverb (for example, in addition to *She cracked a rib* and *It caught a wren* we had *I broke a rib once* and *We saw a wren here*). This manipulation also 'worked', in the sense that many of the sentences were produced with the nuclear accent where we expected, though we did have to discard a larger proportion of utterances than in Experiments 1 and 2.

This modification of the materials to include sentences with final post-nuclear adverbs is also relevant to the issue of 'proportional invariance' in alignment, just mentioned in connection with the interpretation of the results of Experiment 2. As we noted, there have been various suggestions (e.g. Silverman & Pierrehumbert, 1990) that the alignment of accent peaks is not determined relative to some specific landmark in the accented vowel, but is in some way proportional to the duration of some phonological constituent such as the accented word or the entire post-accentual stretch of speech. Our data from Experiment 2 do not allow us to explore this explanation in greater depth, because utterance position is confounded with word structure; that is, we cannot distinguish whether the relevant domain is the word or the post-accentual stretch. By using post-nuclear adverbs, we can compare test words in absolute final position with the same words in nuclear but non-final position.

4.1. Method

Except for the materials and the speakers, the procedures were identical to those in Experiment 2. The materials, as just noted, involved placing the test words in short sentences where they were expected to bear the only accent in the sentence or where the first accent was expected to be markedly less prominent than the nuclear accent. For example:

She chose Neil
He lost a limb
It's made of lead
He broke the lens
We have to kneel now
Check the mail first
Play a reel again
I found Len next

In order not to make the experiment twice as long as Experiment 2, we did not use test words with penultimate stress. Instead, the analysis for stress position is based on a comparison between the conditions 'final' (test word in absolute utterance-final position) and 'penultimate' (test word followed by post-nuclear adverb), replacing the comparison made in Experiment 2 between final word stress and penultimate word stress in the utterance-final word. There were at least 12 test words for each of the four vowels, including a few with final voiced stops like *rib* and *Ned* that we had not used in the previous experiments. We added these to the list of test words because it was difficult to construct plausible short sentences with final adverbs using only the test words from Experiment 2; we were not unduly concerned about the segmental perturbations caused by the final stop, because we now knew that the accent peak occurred fairly early in the test vowel and would therefore be unlikely to be affected. A full list of test words for each vowel is given in Appendix 4. A total of 403 data points were obtained.

The materials were recorded in Edinburgh by students at Edinburgh University, three of whom were speakers of SSE and three of RP. The measurements were again made by RS.

4.2. Results and discussion

As we had hoped, the shorter sentences used in this experiment were normally spoken with only a single prominent pitch accent, and the accent peaks were correspondingly more salient phonetically. This can be seen in Fig. 5. As with Experiment 2, we analysed the data with a $2 \times 2 \times 2$ ANOVA; between-items independent variables were phonological vowel length (short vs. long), stress position (redefined as final vs. penultimate test word position, as just noted), and dialect (SSE vs. RP). Once again separate analyses were performed for the dependent variables VDur, PA-On and PA-Off. The results are summarised in Fig. 6.

In most respects, we replicated the findings from Experiment 2, suggesting that our initial lack of confidence in those data was misplaced. As can be seen from Fig. 6, three observations about alignment based on Experiment 2 hold for Experiment 3 as well. First, we again observed a large numerical difference in alignment between the nuclear peaks of this experiment (32 ms after vowel onset or 100 ms before vowel offset) and the prenuclear peaks of Experiment 1 (75 ms after vowel onset or 6 ms before vowel offset). Second, we found once again that f_0 peaks in SSE were aligned later than in RP, for both measures of peak alignment, PA-On (SSE: 37 ms after vowel onset; RP: 26 ms after vowel onset; $F(1,395) = 9.69$, $p < 0.001$) and PA-Off (SSE: 88 ms before vowel offset; RP: 131 ms before vowel offset; $F(1,395) = 91.49$, $p < 0.001$). Third, despite the change in the materials, we once again observed a difference between the alignment of our English nuclear peaks and the alignment reported in the Dutch data of Schepman et al. (2006). Specifically, if we compare the 'penultimate' condition in Experiment 3 with the monosyllables from Schepman et al. (2006) (i.e. if we compare the conditions in which a monosyllabic nuclear-accented word is followed by a post-nuclear word), we find that in English the peak is aligned on average 38 ms after vowel onset or 74 ms before vowel offset, as against 76 ms after vowel onset or 35 ms before vowel offset in Dutch. This suggests that the difference in alignment between our English data in Experiment 2 and the Schepman et al. Dutch data is not due to any difference in the experimental materials, but reflects a difference between the two languages. Once again, we acknowledge that this conclusion is not based on a direct statistical comparison across studies, but the fact that the experiments were methodologically very similar makes it plausible that the difference is genuine.

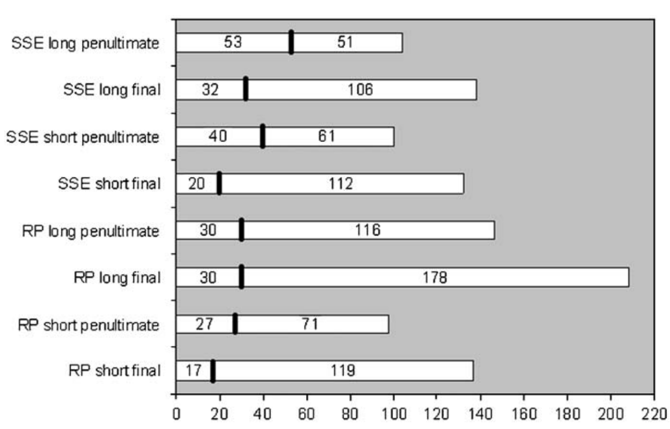

Fig. 6. Means for Experiment 3. The white bars represent vowel duration, and the heavy vertical lines across the bars represent the location of H (the accentual f_0 peak). The numbers in portions of the bars represent the duration of the relevant intervals in ms; the number to the left of the heavy vertical line corresponds to PA-On and that to the right to PA-Off. RP = Received Pronunciation (English), SSE = Scottish Standard English; long and short refer to phonological vowel length, while final and penultimate refer to the position of the stressed syllable relative to the end of the utterance.

With regard to whether there is an effect of vowel length on alignment in nuclear accents, we again found significant effects of vowel length on VDur (short: 116 ms; long: 148 ms; $F(1,395) = 87.64$, $p < 0.001$), and on PA-Off (short: 90 ms before vowel offset; long: 111 ms before vowel offset; $F(1,395) = 29.79$, $p < 0.001$). This appears to suggest that peaks were aligned earlier with vowels of greater duration. However, the results for PA-On in Experiment 3 contradict those from Experiment 2: we found that peak alignment relative to the onset of the vowel (PA-On) is significantly *later* with long vowels (short: 26 ms after the vowel onset; long: 37 ms after the vowel onset; $F(1,395) = 11.1$, $p < 0.001$). This discrepancy makes it difficult to be very confident that there is any effect of vowel length on the alignment of nuclear accent peaks. Undoubtedly, the flatter peaks in Experiment 2 made for more difficult measurement of alignment and hence greater variance in the means in our data, so we might consider the results of Experiment 3 more reliable, and the Experiment 3 results are certainly consistent with a proportional account of alignment in nuclear accents. But without a great deal more data it is probably unwise to attempt to draw more definite conclusions.

With regard to the effect of stress position (final vs. penultimate), it is noteworthy that there is no obvious difference between Experiments 2 and 3, even though the stress-position variable itself was redefined. In Experiment 3, exactly as in Experiment 2, vowels were longer in final position than in penultimate position (final: 154 ms; penultimate: 112 ms; $F(1,395) = 144.42$, $p < 0.001$), and peak alignment was earlier in final than penultimate position, again by both measures, PA-On (final: 25 ms after vowel onset; penultimate: 38 ms after vowel onset; $F(1,395) = 15.66$, $p < 0.001$) and PA-Off (final: 129 ms before vowel offset; penultimate: 74 ms before vowel offset; $F(1,395) = 184.38$, $p < 0.001$). This suggests that the effect of position is driven by adjacency to intonational boundaries rather than simply the edge of the word. That is, a plausible interpretation of Experiment 2 on its own could be that nuclear accents are aligned relative to the whole word: the differences in alignment and vowel duration between the final-stress and penultimate-stress conditions involves adjustments *within the utterance-final word*. However, comparison of the data for Experiments 2 and 3 suggests that these adjustments are independent of word structure, because in Experiment 3 the word is utterance-final in the final-stress condition and not in the penultimate-stress condition, yet the differences are comparable in both experiments. The adjustments must be due primarily to the upcoming phrase boundary.

Finally, for the sake of completeness, we report two significant two-way interactions involving dialect. To some extent they replicate interactions already found in Experiment 2 and appear to reflect the different patterns of vowel duration in RP and SSE. No other interactions reached significance.

First, dialect interacted with vowel length, for VDur and PA-Off ($F(1,395) = 61.61$, $p<0.001$). Short vowels in SSE and RP were almost identical in duration (SSE: 115 ms; RP: 117 ms), but long vowels differed greatly for the two dialects (SSE: 121 ms; RP: 176 ms). Correspondingly, for PA-Off, the difference due to dialect was small for short vowels (SSE: 84; RP: 95 ms before the vowel offset), but great for long vowels (SSE: 78; RP: 145 ms before the vowel offset).

Second, as in Experiment 2, dialect interacted with stress position, for VDur ($F(1,395) = 6.93$, $p<0.01$) and PA-On ($F(1,395) = 6.33$, $p<0.05$). The effect of position on VDur was somewhat larger in RP (final: 173 ms; penultimate: 123 ms) than in SSE (final: 135 ms; penultimate: 102 ms), while the effect of position on PA-On was much larger in SSE (final: 26 ms; penultimate: 46 ms) than in RP (final: 24 ms; penultimate: 29 ms).

We do not believe that these interactions undermine the overall picture of the results we have presented so far. Indeed, the second interaction arguably provides further support for the idea that nuclear alignment is affected by tonal crowding: in SSE, there is less final lengthening, so there is a bigger difference between the final-stress and penultimate-stress conditions in the amount of time pressure from the upcoming utterance boundary; in RP, there is more final lengthening, which relieves some of the time pressure in the final-stress condition.

In summary, Experiment 3 adds three main points to our discussion of Experiment 2. First, by being based on materials that are more directly comparable to those of Schepman et al. (2006), the experiment increases our confidence in the conclusion that nuclear accent peaks are aligned earlier in English than in Dutch. Second, by showing that the stress-position variable (final-stress vs. penultimate-stress) has the same effects on alignment in Experiments 2 and 3, even though stress position was defined relative to the word in Experiment 2 and to the utterance in Experiment 3, our findings suggest that the alignment of nuclear peaks is affected by time pressure at the level of the phrase or utterance. This in turn makes it more plausible that the alignment difference between nuclear and prenuclear accents is due to tonal crowding from the upcoming phrase-final pitch fall. Third, because of the small and contradictory effects for peak alignment relative to vowel onset (PA-On), our findings decrease the plausibility of Schepman et al.'s conclusion that peak alignment in nuclear accents is directly influenced by vowel length, while remaining consistent with an account based an invariant proportion of some segmental stretch beginning with the accented vowel. However, the details remain unclear.

5. General discussion

We have presented the results of three experiments on the alignment of pitch accent peaks in two varieties of British English. We have added to the now substantial body of evidence that the alignment of f_0 features with segmental landmarks is a phonetic parameter on which languages and language varieties can differ, and have provided evidence from new language varieties for the common observation that nuclear accents are aligned earlier than prenuclear accents. In our opinion, both these conclusions are now reasonably well established facts about the alignment of accent peaks at least in the European languages.

More specifically, we have investigated the effect of vowel length on alignment with both nuclear and prenuclear accents, and the effect of stress position with nuclear accents. With regard to the first of these, our findings for English mirror the findings of Schepman et al. (2006) for Dutch: there is a clear effect of vowel length on alignment in prenuclear accents, arguably related in some way to syllable structure, but it is difficult to demonstrate the existence of any such effect for nuclear accents. Together with the fact that alignment is earlier with nuclear accents than with prenuclear accents, this reinforces the conclusion that there is some essential difference between nuclear and prenuclear accents that requires explanation. As noted in the introduction, some investigators (e.g. Face, 2002) have proposed to treat this difference as a matter of different tonal composition, while others have suggested that it results from some kind of time pressure (e.g. Silverman & Pierrehumbert, 1990) or tonal crowding from the upcoming phrase accent or phrase-final fall (e.g. Hualde, 2002). Our results favour the latter type of explanation, for two reasons. First, the failure to find an effect of vowel length on peak alignment with nuclear accents, together with the earlier alignment of nuclear peaks, suggests that any underlying effect of vowel length may be overridden by the need to align the nuclear peak early enough to execute the phrase-final fall. Second and more important, we find a clear effect of stress position both on the duration of the accented vowel and on peak alignment, and the comparison between Experiments 2 and 3 makes it fairly clear that the effect is to be understood in terms of the adjacency of the accented syllable to the end of the phrase or utterance, rather than as a matter of adjustments within the phonological word.

Finally, it seems clear that we still have some way to go before we understand the nature of the structural effects on the alignment of prenuclear accent peaks. Although the most obvious difference between the long-vowel and short-vowel test words in Experiment 1 involves syllable structure, there are, as we noted in Section 2.2.6, two versions of an explanation based on syllable structure, one involving syllable boundaries and one involving syllable weight—and in addition there remains the possibility that the whole idea of dependence on syllable structure is actually illusory. Though our evidence weakly favours the syllable-weight explanation, it seems clear that further empirical work will be necessary to decide this issue, and experiments based on controlled speech materials may not be adequate to the task. In principle it should be easy enough to extend our Experiment 1 materials to include test words with short vowels in checked syllables (e.g. in addition to test words like *seemingly* and *limited* include words like *Wilmington*). However, there are two problems, one practical and one theoretical. Practically, there are very few words like *Wilmington* in which the accented syllable is closed by a sonorant and the following syllable begins with another sonorant, which is ideally what we would want in order to measure the f_0 peak accurately. Theoretically, even if we found enough words in which we could confidently locate the accentual peak, it is not completely clear what experimental outcomes the two versions of the syllable-structure explanation would predict. 'Aligned some distance after the first mora' and 'based on the location of the syllable boundary' are vague enough that they would be difficult to distinguish empirically—in the case of *Wilmington*, it might involve a difference between 'some time after the beginning of the /l/' and 'near the end of the /l/'. It may be that a more promising approach would be a semi-automatic procedure that fits smoothed contours to f_0 contours from spontaneous speech and measures the alignment relative to the landmarks in an automatic segmentation, which would allow us to examine much larger sets of data. In any case there is plenty of scope for further research.

Acknowledgements

The work reported here was supported by the UK Economic and Social Research Council (ESRC) as part of the project 'Alignment of Fundamental Frequency Targets in English and Dutch', Grant no. R000-23-7447 to Edinburgh University (Principal Investigator: D. R. Ladd), and by a British Academy small grant to Edinburgh University for the project 'Intonational alignment and phonological vowel length in Southern British and Scottish English' (Principal Investigator: D. R. Ladd). Thanks are due to Mike Bennett, Eddie Dubourg, Ziggy Campbell and Cedric Macmartin of the ever-helpful technical staff in Linguistics and English Language at Edinburgh for their advice and assistance, and to three anonymous referees for *Journal of Phonetics* who made suggestions leading to significant improvements in the paper.

Appendix 1

As noted in the text, our experiments were conceived as a way of finding phonetic evidence for classifying SSE vowels as long or short, but failed to reach any such conclusion. For the benefit of researchers who may wish to pursue this line of enquiry, the two tables below briefly report descriptive data for the full set of vowels studied in the unreported replication of Experiment 1 (see Section 2.2.3) and in Experiment 3. Further details were reported at the 13th Manchester Phonology Meeting in 2005; a detailed summary handout is available from the first author's web page.

Table A1 shows the alignment of the peak of the prenuclear accents studied in the Experiment 1 replication,

Table A1
Mean peak alignment for prenuclear accents with the ten SSE vowel phonemes studied in the replication of Experiment 1, expressed as proportion of the total CVC string.

Vowel	Keyword	Alignment (proportion of CVC)	Vowel	Keyword	Alignment (proportion of CVC)
ʌ	STRUT	1.07	ʉ	FOOT	0.91
ɪ	KIT	1.00	ɑi	PRICE	0.88
ɑ	TRAP	0.94	o	GOAT	0.86
ɒ	LOT	0.93	i	FLEECE	0.78
ɛ	DRESS	0.92	e	FACE	0.76

Table A2
Mean vowel duration (in ms) for the ten SSE vowel phonemes studied in the Experiment 1 replication and in Experiment 3, averaged over prenuclear (Experiment 1 replication) and nuclear (Experiment 3) accents.

Vowel	Keyword	Vowel duration in ms	*N*	Vowel	Keyword	Vowel duration in ms	*N*
ɪ	KIT	66	188	o	GOAT	109	153
ʌ	STRUT	84	157	ɒ	LOT	110	198
ʉ	FOOT	91	193	ɛ	DRESS	112	208
i	FLEECE	92	233	ɑ	TRAP	123	214
e	FACE	109	214	ɑi	PRICE	147	190

N is the number of observations per vowel.

expressed as a *proportion* of the total duration of the CVC string at the accented syllable. (For example, a value of 1.00 means that the peak was aligned on average at the end of the post-accentual consonant; a value of 0.75 means that the peak was aligned three-quarters of the way from the beginning of the accented syllable to the end of the post-accentual consonant.) This particular method of quantifying alignment was an attempt to allow for the big differences in vowel duration and the possible effects of syllable structure discussed in the text, and we report it here because it yielded the most orderly set of data for the ten vowels under consideration. The vowels are listed in order from the latest alignment to the earliest. It can be seen that those vowels with higher values (i.e. alignment later in the CVC string) are plausibly short, and those with lower values (i.e. alignment earlier in the CVC string) are plausibly long; note in particular that the vowel of STRUT, the only unambiguously short vowel other than KIT and DRESS, shows late alignment. However, there is no clear grouping into two categories.

Table A2 shows mean duration values for all the vowels in both the Experiment 1 replication and in Experiment 3, i.e. averaging across nuclear and prenuclear accents in both final and penultimate position. The vowels are listed in order of increasing duration. It can be seen that the main influence on vowel duration in SSE appears to be vowel height, not vowel length. Note that the members of putative long-short pairs /e–ɛ/ (FACE/DRESS) and /o–ɒ/ (GOAT/LOT) are virtually identical in mean duration.

Appendix 2. Test words listed by primary stressed vowel for Experiment 1

FLEECE	KIT	FACE	DRESS
achievable	cinema's	amazingly	chemical
believable	clinical	attainable	cleverly
conveniently	criminal	available	democrat
evenly	cynical	behavioural	emigrant
feverish	finicky	brazenly	eminent
hygienically	finishing	containable	enemy
lenient	gimmicky	famously	evident
leniently	imminent	flamingly	feminist
meaningful	limited	flavourless	generous
meaningless	militant	heinously	genuine
perceivable	mineral	ravingly	heavenly
pleasingly	minimal	scathingly	heavily
redeemable	minimum	slavishly	menacing
screamingly	minister's	spontaneously	perennial
seasonal	minuscule	sustainable	senator's
seemingly	similar	unwavering	venomous
unfeelingly		wavering	

Appendix 3. Test words listed by primary stressed vowel for Experiment 2

FLEECE	KIT	FACE	DRESS
Final stress			
Eel	ill	Elaine	Amen
Kneel	limb	lame	Knell
Lean	Lynn	lane	Laing
Meal	mill	mail	Len
Mean	nil	male	Lens
Neil	rim	mane	Mel
reel	ring	nail	Men
unreal		name	men's
			Nell
			Wren
Penultimate stress			
anaemic	lily	Delaney	Lemon
leaner	limit	mailer	Lennon
leaning	linen	mailing	Leonard
Lima	Linnhe	maimed	mellow
mealy	Miller	railing	Melon
meaning	Millie	raining	Memo
Nina	million	rainy	menace
reeling	minnow	reigning	Relic
remit	minute	remaining	Rennet
		waning	

Appendix 4. Test words listed by primary stressed vowel for Experiment 3

FLEECE	KIT	FACE	DRESS
reel	bib	Elaine	knell
kneel	lip	lame	lead
Neil	limb	lane	leg
mean	Lynn	made	Len
lean	mill	maid	lens
real	nib	mail	Meg
read	nil	main	Mel
need	rib	male	men
Reid	rig	mane	Ned
meal	rim	nail	Nell
knead	ring	name	red
lead	rip	raid	wren
	sill	rain	

References

Arvaniti, A., & Baltazani, M. (2005). Intonational analysis and prosodic annotation of Greek spoken corpora. In S. Jun (Ed.), *Prosodic* *typology: The phonology of intonation and phrasing* (pp. 84–117). Oxford: Oxford University Press.

Arvaniti, A., & Garding, G. (2007). Dialectal variation in the rising accents of American English. In J. Hualde, & J. Cole (Eds.), *Papers in laboratory phonology*, Vol. 9 (pp. 547–576). Mouton de Gruyter.

Arvaniti, A., Ladd, D. R., & Mennen, I. (1998). Stability of tonal alignment: The case of Greek prenuclear accents. *Journal of Phonetics*, *36*, 3–25.

Arvaniti, A., Ladd, D. R., & Mennen, I. (2006). Phonetic effects of focus and "tonal crowding" in intonation: Evidence from Greek polar questions. *Speech Communication*, *48*, 667–696.

Atterer, M., & Ladd, D. R. (2004). On the phonetics and phonology of "segmental anchoring" of f_0: Evidence from German. *Journal of Phonetics*, *32*, 177–197.

Bruce, G. (1977). *Swedish word accents in sentence perspective*. Lund, Sweden: Gleerup.

Bruce, G., & Gårding, E. (1978). A prosodic typology for Swedish dialects. In E. Gårding, G. Bruce, & R. Bannert (Eds.), *Nordic prosody* (pp. 219–228). Lund: Lund University, Department of Linguistics.

Dalton, M., Ní Chasaide, A. (2007). Nuclear accents in four Irish (Gaelic) dialects. In *Proceedings of the 16th international congress of phonetic sciences (ICPhS)*, Saarbrücken, August 2007 (pp. 965–968).

Dilley, L. C., Ladd, D. R., & Schepman, A. (2005). Alignment of L and H in bitonal pitch accents: Testing two hypotheses. *Journal of Phonetics*, *33*, 115–119.

Face, T. L. (2002). *Intonational marking of contrastive focus in Castilian Spanish*. Munich: Lincom Europa.

Giegerich, H. (1992). *English phonology: An introduction*. Cambridge: Cambridge University Press.

Grabe, E. (1998). Pitch accent realisation in English and German. *Journal of Phonetics*, *26*, 129–144.

Hualde, J. I. (2002). Intonation in Spanish and other Ibero-Romance languages: Overview and status quaestionis. In C. Wiltshire, & J. Camps (Eds.), Romance phonology and variation. *Selected papers from the 30th linguistic symposium on romance languages*, Gainesville, FL, February 2000 (pp. 101–115). Amsterdam: Benjamins.

Ishihara, T. (2003). A phonological effect on tonal alignment in Tokyo Japanese. In *Proceedings of the 15th international congress of phonetic sciences*, Barcelona (pp. 615–619).

Ladd, D. R. (2008). *Intonational phonology* (2nd ed.). Cambridge: Cambridge University Press.

Ladd, D. R., Mennen, I., & Schepman, A. (2000). Phonological conditioning of peak alignment in rising pitch accents in Dutch. *Journal of the Acoustical Society of America*, *107*, 2685–2696.

Ladd, D. R., & Schepman, A. (2003). "Sagging transitions" between high pitch accents in English: Experimental evidence. *Journal of Phonetics*, *31*, 81–112.

Lickley, R., Schepman, A., & Ladd, D. R. (2005). Alignment of "phrase accent" low in Dutch falling rising questions: Theoretical and methodological implications. *Language and Speech*, *48*, 157–183.

Nibert, Holly (2000). *Phonetic and phonological evidence for intermediate phrasing in Spanish.* Ph.D. Thesis, University of Illinois, Urbana-Champaign.

Nooteboom, S. G., & Slis, I. H. (1972). The phonetic feature of vowel length in Dutch. *Language and Speech*, *15*, 301–316.

Peterson, G. E., & Lehiste, I. (1960). Duration of syllable nuclei in English. *Journal of the Acoustical Society of America*, *32*, 693–703.

Prieto, P., van Santen, J., & Hirschberg, J. (1995). Tonal alignment patterns in Spanish. *Journal of Phonetics*, *23*, 429–451.

Prieto, P., & Torreira, F. (2007). The segmental anchoring hypothesis revisited. Syllable structure and speech rate effects on peak timing in Spanish. *Journal of Phonetics*, *35*, 473–500.

Schepman, A., Lickley, R., & Ladd, D. R. (2006). Effects of vowel length and "right context" on the alignment of Dutch nuclear accents. *Journal of Phonetics*, *34*, 1–28.

Schiller, N. O., Meyer, A. S., & Levelt, W. J. M. (1997). The syllabic structure of spoken words: Evidence from the syllabification of intervocalic consonants. *Language and Speech*, *40*, 103–140.

Silverman, K., & Pierrehumbert, J. (1990). The timing of prenuclear high accents in English. In J. Kingston, & M. Beckman (Eds.), *Papers in laboratory phonology I* (pp. 72–106). Cambridge: Cambridge University Press.

Steele, S. (1986). Nuclear accent f_0 peak location: Effect of rate, vowel, and number of syllables. *Journal of the Acoustical Society of America*, *80*(Suppl. 1), s51.

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

Wells, J. C. (1982). *Accents of English*, Vol. 1. Cambridge: Cambridge University Press.

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