The production and representation of fake geminates in English

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Abstract

The current study focused on the production of fake geminates across different boundary types in English to investigate the hypothesis that word-internal fake geminates may differ from those that arise across a word boundary. In this study, word-internal geminates arising from affixation, and described as either assimilated or concatenated, were matched to fake geminates arising from sequences of identical consonants that spanned a word boundary and to word-internal singletons. The findings were word-internal fake geminates were found to be longer than matched singletons in absolute and relative terms. By contrast, geminates that occurred at word boundaries were only longer than matched singletons in absolute terms. In addition, fake geminates in two word phrases were typically "pulled apart" in careful speech; that is, speakers marked the boundaries between free morphemes with pitch changes and pauses. Morpheme boundaries in words with bound affixes were very rarely highlighted in this way. These results are taken to indicate that word-internal fake geminates are represented as a single long consonant in the speech plan rather than as a consonant sequence. Only fake geminates that arise in two word phrases exhibit phonetic characteristics that are consistent with the representation of two identical consonants crossing a morpheme boundary.

Keywords: geminates; fake geminates; consonantal duration; juncture cues.

1. Introduction

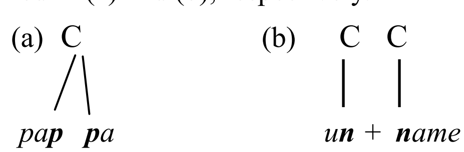
True geminates are phonetically long segments that contrast with phonetically short segments in a phonemic inventory. Fake geminates are phonetically long segments that are not contrastive. The latter segments arise when morpheme concatenation results in a sequence of two identical segments. The current study focuses on these accidentally long segments in English to investigate the phonetic representation of segmental duration in a language that does not have a length contrast.

1.1. True versus fake geminates

There are three types of geminates in the world's languages: lexical, assimilated, and concatenated. Lexical geminates are given in the lexicon and are part of the phonemic inventory (e.g. [pap:a] 'mush' vs. [papa] 'pope' in Italian). Assimilated geminates arise when one segment takes on the identity of the preceding or following segment at a word-internal morpheme boundary (e.g. *cheon+li* → [t□ □l:i] 'the law of nature' in Korean). Concatenated geminates arise from identical consonant sequences that span a morpheme boundary within a word or in a phrase (e.g. *un+named, fun name*). Gemination can also arise through morphological derivation (e.g., Arabic).

True geminates are distinguished from fake geminates in that, even when spanning a morpheme boundary, segmental length in one word distinguishes it from an otherwise identical word in the inventory. For example, the Korean word [t□ □l:i] 'the law of nature' is distinguished from [t□ □li] 'handling' by segmental length rather than by morphology because the archaic Chinese morphemes from which [t□ □l:i] and [t□ □li] were derived historically are not accessed by native Korean speakers during comprehension (see Cho, 2001). This example from Korean can be contrasted with the situation in English where segmental length never serves to distinguish meaning in otherwise phonologically identical words.

Autosegmental phonology captures the difference between true and fake geminates as a difference in the number of underlying feature bundles involved. True geminates are represented as a single feature bundle that is linked to two timing units, whereas fake geminates are represented by a sequence of feature bundles with each bundle linked to its own unit (see McCarthy, 1986). The representations of true and fake geminates are illustrated in (a) and (b), respectively.



The phonological representation suggests that differences between true and fake geminates will not be manifested in absolute timing differences at the phonetic level, since both are associated with two timing units (though see Payne, 2005, for an alternative view). Such a suggestion is supported by phonetic studies that have compared the absolute duration values of true and fake geminate consonants in Estonian (Lehiste, Morton, & Tatham, 1973), Levantine Arabic (Miller, 1987), Bengali (Lahiri & Hankamer, 1988), and Tashlhiyt Berber (Ridouane, 2010) and found no difference between the two geminate types.

Although true and fake geminates may be indistinguishable from one another in terms of absolute consonant duration, a few studies indicate that they may be distinguished by relative duration [i.e., singleton-to-geminate duration (Miller, 1987), vowel-to-consonant duration (Ridouane, 2010)]. For example, Ridouane found that vowels that precede true geminates are shorter than those that precede fake geminates in Tashlhiyt Berber. Since absolute consonant duration was the same for true and fake geminates, the preceding vowel duration differences translate into relative duration differences between true and fake geminates, such that true geminates were longer than fake geminates. The finding that true and fake geminates might be distinguished by a ratio of consonant to preceding vowel duration (C:V1) is intuitively satisfying because it parallels a finding in the literature on phonemic length perception; namely, that C:V1 duration provides a robust higher-order cue to the singleton/geminate contrast in Italian and Japanese (Pickett, Blumstein, & Burton, 1999; Idemaru & Guion, 2008).

As interesting as the Tashlhyit Berber results are, they nonetheless conflict with those reported by Lahiri and Hankamer (1988), who found no preceding vowel duration differences for true and fake geminates in Bengali. The conflicting results may, however, be due to a difference in the types of fake geminates that were examined in the two studies. Whereas Ridouane (2010) examined fake geminates that arose across a word boundary, Lahiri and Hankamer examined fake geminates that arose through affixation. It is likely that a word boundary would trigger boundary-adjacent syllable lengthening, which would explain the longer preceding vowel durations that Ridouane observed for fake geminates. If boundary-adjacent lengthening does not occur, then true and fake geminates could have the same preceding vowel durations, just as Lahiri and Hankamer observed for Bengali. If true and fake geminates do not differ in preceding vowel duration or in absolute consonant duration, then they will also have the same relative (C:V1) durations.

Along with many others (e.g., Lehiste, 1970; Klatt, 1976; Wightman, Shattuck-Hufnagel, Ostendorf,

& Price, 1992; Turk & Shattuck-Hufnagel, 2000; Keating, Cho, Fougeron, & Hsu, 2003; Byrd & Saltzman, 2003), we assume that boundary adjacent lengthening occurs because boundaries are represented in the speech plan. We define the speech plan in the way that Levelt (1989:Ch.8) and many others have done; namely, as the multi-word phonetic plan that allows for fluent speech.

When our assumptions regarding boundaries are applied to make sense of Ridouane's (2010) and Lahiri and Hankamer's (1988) conflicting results, then the prediction is that word boundary fake geminates will differ from word-internal fake geminates even though both types emerge from morpheme concatenation. This prediction follows from the view that the different types of fake geminates are differently represented in the speech plan. Specifically, fake geminates that cross a word boundary are represented as a sequence of identical consonants, consistent with the traditional view of these segments. Such a representation will be phonetically indicated by juncture cues, such as boundary-adjacent lengthening, which result in fake geminates having shorter relative durations than true geminates. Word-internal fake geminates are represented as long consonants in the speech plan, in the same way as true geminates. This representation will be phonetically indicated by relative durations that are longer than those associated with word-boundary fake geminates and by a lack of phonetic boundary cues.

Our proposal that morpheme boundaries are absent in the phonetic representation that guides speech production would seem to be at odds with the finding of phonetic length differences of affixes in heteromorphemic words that vary systematically in their relative decomposability (Hay, 2007). Such a finding adds to many others that support a large class of dual-route processing models, which assume lexical representations that are both holistic and morphologically decomposed (Wurm, 1997; Schreuder & Baayen, 1995; Hay, 2002; Niswander-Klement & Pollatsek, 2006). Lexical items are accessed either directly in their holistic form or indirectly via their constituent morphemes depending on how decomposable they are. Lexical items that have higher decomposability ratios are preferentially accessed via their parts than those that have lower decomposability, which are in turn preferentially accessed as whole items. If the dual route model is relevant to the phonetic representation of items selected for implementation, then we might expect that the phonetic behavior of word-internal fake geminates will be the same as that for word-boundary fake geminates when the word-internal geminates occur in heteromorphemic words with high decomposability ratios. This would suggest that not all word-internal fake geminates have the same speech plan representation and so they may not all have the same phonetic signature. Word internal fake geminates that emerge in highly decomposable words may be represented as a sequence of two consonants, and so should pattern with word boundary geminates. Fake geminates that occur in less decomposable words may be represented as a single long consonant, and so should pattern differently from word boundary fake geminates.

1.2. Current Study

The current study focused on the production of fake geminates across different boundary types in English to investigate the hypothesis that word-internal fake geminates may differ from those that arise across a word boundary. Word-internal fake geminates arising from affixation were compared to phrases with word boundary geminates and to words with singletons. Speech style was manipulated as a means of exploring representation via the phonetics. This method of exploration follows from Johnson, Flemming, and Wright's (1993) assumption that careful, or hyperarticulated, speech makes obvious speech plan representations, which are often otherwise obscured through phonetic reduction in normal speech. Whereas Johnson et al. are explicit in their statement of this assumption, they note that most of the work that has investigated style-dependent production differences is guided by the same assumption (e.g., Moon & Lindblom, 1994; van Son & Pols, 1999; Smiljanic & Bradlow, 2005; Kang & Guion, 2008). Our expectation was that speakers' careful productions would highlight the representation underlying fake geminates and that these productions would therefore result in either greater consonantal length differences between singletons and fake geminates, or in the phonetic marking of morpheme boundaries in words or phrases with fake geminates, or both depending on the representation.

The effect of decomposability on production was also tested. Word-internal assimilated fake geminates were compared to word-internal concatenated fake geminates. Assimilated geminates arise in English with the Latinate prefix *in-* (e.g., *immoral*), whereas concatenated geminates arise with the Germanic prefix *un-* (e.g., *unnamed*). The Latinate and Germanic prefixes differ in that the former are more idiosyncratic and structure-changing than the latter, consistent with their division in Lexical Phonology into level 1 versus level 2 affixes (see Hay, 2002; Plag, 2003). The Lexical Phonological division of affixes into different levels references differences in "the productivity of participating morphemes, order of attachment, and their phonological interaction with the roots" (Vannest & Boland, 1999: 324). A corpus study by Baayen and Renouf (1996) confirms that the level 1 Latinate prefix *in-* is indeed less productive than the level 2 Germanic prefix *un-*. The Latinate prefix *in-* also has a smaller prefix likelihood value (.094) than the Germanic prefix *un*- (.283), as calculated by the number of English words beginning with the sequence *in*- or *un*- divided by the number of words with *in*- or *un*- prefixes (Wurm, 1997). Words with prefixes that are unproductive and have low prefix likelihoods are more likely to be accessed in composite form (as whole items) than words with prefixes that are productive and have high prefix likelihoods (*ibid*). If this suggestion is correct, then *in*- and *un*- prefixed words may have different speech plan representations with regards to boundary information, which should lead to different phonetic outcomes: the production of fake geminates in *un*- prefixed words should pattern with the production of word boundary fake geminates, whereas the production of fake geminates in *in*- prefixed words should resemble that associated with true geminates.

2. Methods

2.1. Participants

Eight University of Oregon undergraduate students (4 males and 4 females) participated. All of the participants were native speakers of American English who reported normal hearing. Participants were compensated with course credit for their time.

2.2. Stimuli

The stimuli were 24 English words, all of which were found in the Webster's online Dictionary (2008). The words with singleton consonants and the phrases with word boundary geminates were chosen to match the words with word-internal geminates in terms of lexical stress and spelling—all geminate and singletons were spelled with double *m*'s or *n*'s (see Table 1).

Table 1 about here.

The words *annoyed* and *unnamed* have been previously identified as a singleton and fake geminates (Kaye, 2005). The other words, including the matching words with singletons, were selected and categorized by the first author, who is a native speaker of Korean—a language with a phonemic durational contrast (Han, 1996; Choi & Jun, 1998). This author's perceptions of nasal length were confirmed by asking 10 other native Korean speakers to judge nasal length in the selected words, using the following procedure: A female native American-English speaker, who was naïve to the purpose of the study, was asked to produce the stimuli listed in Table 1 in the frame sentence, *I said* ____ *again*. The speaker's productions were recorded and then played back in random order to the 10 Korean listeners, who were instructed to rate the relative duration of /n/ and /m/ in each word on a 7 point scale (1 = extremely short, 7 = extremely long). The rating results were consistent with the first author's categorizations of the stimuli. Korean listeners rated singleton nasals as much shorter than word-internal geminate nasals (singletons, $M = 1.9$, $SD = .56$; word-internal geminates, $M = 5.2$, $SD = .68$). Word boundary geminate nasals were determined to be even longer than word-internal geminate nasals (word boundary geminates, $M = 6.1$, $SD = .63$).

The reader will note that at least two of the 8 words in Table 1 that were determined to contain singletons are obviously prefixed (*immigrational* and *innerve*). That is, these words contain unbound stems, just like the words with geminates. The words *immigrational* and *innerve* were chosen, like all the others, to match the words with fake geminates in lexical stress and spelling. However, their status as singleton consonants suggests that our notion of decomposability and its effects on representation and production may be simplistic. In particular, it could be that decomposability is gradient rather than categorical (see, e.g., Hay & Baayen, 2005). If this is the case, then a simple comparison of assimilated to concatenated geminates may not provide a complete test of the effect of decomposability. The analyses took this into account by entering lexical item as a random factor.

Along these lines, it is worth noting that when we calculated relative decomposability following Hay (2001) we found that the mean decomposability ratio for *in*- prefixed words was lower than that for *un*- prefixed words (0.42 versus 0.56). We also found substantial variability within each category. This variability is shown in Table 2. The relative decomposability of individual lexical items in Table 1 is expressed on a scale from 0 to 1, with 0 representing non-decomposable items and 1 representing completely decomposable items. The exact values were obtained by calculating the frequency ratio of the base item to that of the whole item and then dividing by 100. Heteromorphemic words with base items that were at least 100 times more frequent than the whole word were assigned a decomposability value of 1. Base and whole item frequency ratios were calculated separately based on word frequencies in the Corpus of Contemporary American English (COCA) and in Google. The ratios presented in Table 2 are the average values for the two corpora.

Table 2 about here.

2.3. Procedure

The 24 words shown in Table 1 were embedded in the carrier phrase, *I said* ____ *again*, randomly ordered into 3 different lists of phrases, with each list representing a single repetition of all 24 items. Each speaker was given several minutes to look over the stimuli before recording began. Unfamiliar words were defined and produced by the experimenter for the speaker. The experimenter then explained that speakers would be producing each phrase in their normal speaking style as well as in a careful speaking style. The careful speaking style was explained as being the clear speech style one might use with a foreigner. Once speakers were comfortable with the stimuli list and understood the style instructions, recording began. Speakers first produced the phrase in a normal style. The experimenter then asked, *What did you say?*, which was the speaker's cue to produce the same sentence using a careful style. In this way, all speakers produced 72 phrases twice, yielding a total of 144 productions per speaker.

All recordings were made in the sound-insulated booth in the University of Oregon's Phonetic-Phonology Laboratory using a SHURE SM10A microphone and Marantz PMD660 solid state recorder. The recorded utterances were saved in digital format, for later analysis.

2.4. Measurements

The spoken phrases were displayed in Praat as oscillograms and spectrograms. Acoustic duration of the first vowel and relevant nasal consonants was measured to obtain absolute and relative duration measures. Non-durational boundary cues were also investigated. Fundamental frequency (F0) contours were tracked across the relevant VC(C)V sequences and the presence or absence of pauses was noted. The segmentation criteria that guided acoustic measurement and pause identification were as follows.

Nasal-vowel boundaries were identified in the waveform by a drop in acoustic energy, a drop in F1, the significant diminishment of F2 and near absence of higher formants. The absolute duration of the preceding vowel and subsequent nasal was calculated based on the segmentation procedure. When a pause intervened at a word or morpheme boundary, total nasal duration was calculated as the sum of preceding and following nasal duration. The relative duration of nasals was calculated using the measure that best distinguishes singleton and nasals in languages with phonemic duration (Pickett, Blumstein, &

Burton, 1999; Idemaru & Guion, 2008); namely, as the proportion of total nasal duration to preceding vowel duration (C:V1).

F0 duration was measured at 8 points across the relevant VC(C)V sequence: preceding vowel onset, midpoint, offset, syllable 1 offset, syllable 2 onset, following vowel onset, midpoint, and offset. The syllable 1 offset and syllable 2 onset measures were taken at the offset and onset of nasal duration, if a pause occurred, or before and after a discontinuity in the nasal portion of the waveform (see Figure 1), or on either side of a midpoint in nasal duration, if no pause or discontinuity were present.

Figure 1 about here.

2.5. Analyses

Mixed effect models were used to evaluate the differences between singletons, word-internal geminates, and word boundary geminates as well as the differences between word-internal assimilated and concatenated geminates due to *in*- versus *un*- prefixing. The dependent variables in these analyses were (1) absolute nasal duration, (2) relative nasal duration, and (3) the difference in F0 across the syllable boundary. Consonant type (singleton, word-internal geminate, word boundary geminate) and prefix type were fixed factors in the models. Speaker and item were included as random factors. In all cases, the effects of the fixed and random factors on the dependent variables were first evaluated for normal and careful speech separately. The effect of speech style was then evaluated in analyses on the difference in values (absolute duration, relative duration, and F0) between careful and normal styles.

3. Results

The results suggest that speech plan representations encode word-internal singletons and assimilated geminates similarly and distinctly from word boundary geminates. The absolute duration of all word-internal fake geminates was greater than that of singletons in normal and careful speech, but only the relative duration of word-internal fake geminates was greater than that of word-internal singletons across speaking styles. Assimilated and concatenated geminates also differed in absolute duration in normal and careful speech, but not in relative duration regardless of speaking style. F0 contours showed clear disjuncture in phrases with word boundary geminates and some disjuncture in careful speech for words with *un*- prefixes. Moreover, in careful speech, the majority of two word phrases were uttered with a pause between the first and second word as were a small percentage of *un-* prefixed words with concatenated geminates. No disjuncture was evident in words with singletons or in *in-* prefixed words with assimilated geminates. These results are presented in more detail below.

3.1. Geminate duration

The first set of analyses focused on the absolute and relative duration of word-internal geminates and their consonant-matched singleton and word boundary counterparts. The expectation was that all fake geminates would be longer than singletons, but that word-internal geminates would differ from word boundary geminates if their speech plan representations differed.

3.1.1. Absolute consonant duration

Table 3 about here.

Table 3 summarizes the effect of consonant type (singleton, word-internal geminate, word boundary geminate) on absolute duration in (a) normal speech, (b) careful speech, and (c) on the difference in absolute duration between careful and normal speech. Each of the analyses also included random intercepts for speaker (a. $SD = 10.96$; b. $SD = 14.02$; c. $SD = 10.29$) and for item (a. $SD = 10.62$.; b. $SD = 18.41$; c. $SD = 12.05$) as well as residual error (a. $SD = 17.31$; b. $SD = 32.04$; c. $SD = 34.26$). Figure 2 displays the effect of consonant type for normal and careful speaking styles by items, which are in turn arranged from least to most decomposable within each type.

Figure 2 about here.

Figure 2 shows that word-internal geminates were significantly longer than singletons in normal speech ($p < 0.01$) and that this difference was especially pronounced in careful speech ($p < 0.01$). Word boundary geminates were not significantly different from word-internal geminates in either normal ($p = 0.53$) or careful speech ($p = 0.07$). The difference between word-internal geminates and singletons was larger in careful speech compared to normal speech ($p < .01$), but the difference between word-internal geminates and word boundary geminates was not significant ($p = 0.15$).

Figure 2 also shows the variable effect of item on absolute duration. For example, the middle panel indicates substantial variability in word-internal geminate duration for the rightmost 4 items, which were also the most decomposable items (i.e., *immemorial*, *unnerve*, *immeasured*, *unnail*). This variability suggests that the decomposability score associated with individual items had little effect on absolute consonant duration. The by item results shown in Figure 2 do, however, suggest that *un*- prefixed words may have been produced with longer absolute consonant duration than the *in*- prefixed words. To determine whether this effect was significant, we examined the effect of prefix and consonant type on the absolute duration of word-internal geminates. Again, the analyses for (a) normal, (b) careful and for (c) the difference between careful and normal speech included speaker (a. *SD* = 14.27; b. *SD* = 25.28; c. *SD* = 21.22) and item (a. *SD* = 4.00; b. *SD* = 12.87; c. *SD* = 11.60) as random factors as well as a residual error term (a. *SD* = 16.10; b. *SD* = 27.04; c. *SD* = 31.52).

Figure 3 about here.

The effect of prefix type is shown in Figure 3. Average absolute duration values associated with matched singletons and word boundary geminates are shown for comparison. As can be seen in the figure, the word-internal geminates in *un*- prefixed words were significantly longer than the word-internal geminates in *in*- prefixed words in normal [$t(95) = 4.2$, SE = 3.66 , $p < 0.01$] and in careful speech [$t(95) = 4.1$, SE = 9.9 , $p < 0.01$]. The mean value of the difference between un- and in- prefixed words was substantially greater in careful (41ms) speech than in normal speech (14ms). The lengthening of word-internal geminate duration for *un*- relative to *in*- prefixed words in careful speech compared to normal speech was also significant [$t(95) = 2.67$, SE = 9.37, $p < 0.01$].

It is possible that the longer duration of word-internal geminates in *un*- prefixed words compared to *in*- prefixed words may be attributed to intrinsic differences in the duration of /n/ versus /m/ rather than to the concatenated versus assimilated nature of the geminates. This possibility is undercut by the similar mean durations of /n/ and /m/ when these were singleton or word boundary geminates [singleton /n/ 101.4ms (*SD* = 42.3); singleton /m/ = 99.4ms (*SD* = 30.4); word boundary geminate /n/ = 180.94ms (*SD* = 58.4); word boundary geminate /m/ = 175.58ms (*SD* = 53.5)]. Thus, the durational difference between word-internal concatenated and assimilated geminates seems to be due to the prefixes involved.

3.1.2. Relative consonant duration

Table 4 about here.

Table 4 summarizes the effect of consonant type (singleton, word-internal geminate, word boundary geminate) on relative duration in (a) normal speech, (b) careful speech, and (c) on the difference in relative duration between careful and normal speech. The analyses included random intercepts for speaker (a. *SD* = 0.04; b. *SD* = 0.10; c. *SD* = 0.13) and item (a. *SD* = 0.17; *SD* = 0.16; c. *SD* = 0.13), and a residual error term (a. *SD* = 0.28; b. *SD* = 0.35; c. *SD* = 0.38). Figure 4 displays the effect of consonant type for normal and careful speaking styles by items, which are again arranged from least to most decomposable within each type.

Figure 4 about here.

The results on relative duration were substantially different from those on absolute duration in that the relative consonant duration of word-internal geminates was longer than word boundary geminates in normal ($p < 0.01$) and careful speech ($p < 0.01$). Moreover, the durational difference between word-internal and word boundary geminates was exaggerated in careful compared to normal speech ($p < 0.01$). Figure 4 also shows what a post hoc test confirms; namely, that the relative duration of word boundary geminates was similar to that of singletons across speaking conditions [$t(766) = 1.99$, SE = 0.26, $p = 0.47$].

Once again, items were associated with unsystematic variability in duration, suggesting that the decomposability scores associated with each item had little effect on the duration differences observed across consonant types. However, in contrast to the results on absolute duration, an analysis on the relative duration of word-internal geminates that included speaker (a. *SD* = 0.10; b. *SD* = 0.00; c. *SD* = 0.11) and item (a. *SD* = 0.05; b. *SD* = 0.09; c. *SD* = 0) as random factors and a residual error term (a. *SD* = 0.22; b. *SD* = 0.33; c. *SD* = 0.39) also showed no effect of prefix type on geminate duration. As shown in Figure 5, concatenated and assimilated word-internal geminates did not differ in normal [$t(95) = 0.5$, SE = 0.05, $p = 0.62$] or in careful speech [$t(95) = 0.15$, SE = 0.08, $p = 0.88$], and the difference in relative geminate duration between normal and careful speech was also unaffected by prefix type [$t(95) = -0.21$, SE = 0.06, p = 0.83]. The lack of prefix-dependent differences in relative geminate duration supports the previous suggestion that prefix-dependent differences in absolute geminate duration were due to overall differences in the duration of *un-* versus *-in*.

Figure 5 about here.

To summarize, the absolute duration of word-internal and word boundary geminates were similar and substantially different from singleton duration; but once preceding vowel length was taken into account, word-internal and word boundary geminates differed and only word-internal geminates were longer than singletons. In this way, word-internal fake geminates behaved more like true geminates than did word boundary geminates.

3.2. Non-durational Boundary Cues

If word-internal geminates behave like true geminates and unlike word boundary geminates, then we might expect that word-internal geminates are represented in the speech plan in the same way as true geminates; namely, as a single long consonant rather than as a sequence of consonants. Such a representation implies that word-internal boundary information is absent in the plan that guides the execution of fluent speech. In this way, the conclusion that word-internal fake geminates behave like true geminates predicts that intonational and pausing patterns that cue boundaries will be absent in words with internal singletons and geminates, but not in phrases with word boundary geminates. This prediction was upheld in an analysis of the F0 contours and pausing patterns associated with the relevant VC(C)V sequences across the consonant types under investigation.

Figure 6 shows the F0 contours associated with the normal and careful productions of VC(C)V sequences in items with word-internal singletons, word-internal concatenated and assimilated geminates, and in items with word boundary geminates.

Figure 6 about here.

Analyses on F0 differences across the syllable boundary in normal and careful speech confirmed what is evident from the figure; namely, that the contours associated with word-internal geminates and with singletons were similar in normal [$t(287) = -0.12$, SE = 0.08, $p = 0.90$] and in careful speech [$t(287) = -0.51$, SE = 0.66, $p = 0.61$]. By contrast, the contours associated with word-internal geminates and word boundary geminates were different in both normal [$t(287) = 2.14$, SE = 0.08, $p = 0.03$] and in careful speech [$t(287) = -20.48$, SE = 0.47, $p < 0.01$]. The random factor of speaker was associated with somewhat more variability than the random factor of item in the analyses of F0 offset/onset differences in normal (speaker, *SD* = 0.02; item, *SD* = 0.01) and careful speech (speaker, *SD* = 0.41; item, *SD* = 0.00). The residual error terms had standard deviations of 0.09 and 2.33 in normal and careful speech, respectively.

The F0 contours associated with assimilated and concatenated word-internal geminates did not differ in normal speech [$t(95) = -1.70$, SE = 0.01, $p = 0.09$], but *un-* prefixed words showed more evidence of disjuncture than *in-* prefixed words in careful speech [$t(95) = 2.19$, SE = 0.34, $p = 0.03$]. The standard deviations associated with the random intercepts of speaker and item were both 0 in normal speech and 1.47 and 0.51 in careful speech. The standard deviations of the residual errors were 0.82 and 6.45 in normal and careful speech, respectively.

The pause data were consistent with the patterns evident in the F0 data. In careful speech, speakers almost always inserted a pause at the word boundary in phrases with fake geminates (95%). When speaking carefully, speakers also occasionally inserted a pause at the morpheme boundary in *un*- prefixed words (10%), and between the first and second syllable in words with singletons (3%), but never at the morpheme boundary in *in*- prefixed words with assimilated geminates. The pause duration in word boundary geminates was the longest (273ms, *SD* = 115.3). The pause duration in singletons (213ms, *SD* = 55.6) was longer than that in word-internal concatenated geminates (202ms, *SD* = 58.1). When speaking normally, speakers never inserted pauses within a word, but occasionally inserted pauses at word boundaries in the phrases (8%).

Together, the intonational contours and pausing patterns associated with production of the stimuli in normal and careful speech show that word boundaries are highlighted in production, and that the word-internal boundary associated with *un*- prefixed words is more likely to be represented than that associated with *in*- prefixed words.

4. Discussion

The results from the current study suggest that the same sound may be represented with different relative lengths in different English words, even though segmental length is non-contrastive in English. Similar to true geminates, the assimilated fake geminates that occurred in *in*- prefixed words were longer in absolute and relative terms than matched singletons, especially in careful speech. These fake geminates were also never pulled apart in production, even in careful speech. Assuming that careful speech productions highlight speech plan representations, the combined results suggest that English assimilated geminates may be represented as long consonants.

The absence of phonetic boundary cues at the *in*-/root boundary in words with assimilated fake geminates suggests that these boundaries are not represented in the speech plan. This conclusion is consistent with the Lexical Phonological convention known as bracket erasure (Kiparsky, 1982; Mohanan, 1986). According to the bracket erasure convention, word-internal morphological information is removed once the (lexical) phonological rules that interact with morphological structure have applied. In the case of the level 1 *in*- prefix, the morpheme boundary would have been erased after the final nasal in the prefix assimilated to the place of the initial nasal in the root and before being passed out of the lexicon.

Whole word and many dual route models of lexical access also allow for the possibility that morpheme boundaries are absent in the plan that guides fluent speech (e.g., Butterworth, 1983; Bybee, 1985; Wurm, 1997; Laudanna, Burani, & Cermele, 1994; Schreuder & Baayen, 1995; Niswander-Klement & Pollatsek, 2006). For example, Hay (2002) argues that level 1 affixes, such as the *in*- prefix of the current study, are preferentially accessed via a direct route, which would entail that the holistic representations of these words guide their production. Such representations need not in themselves contain information about the constituent structure of the item. If the holistic representations do not contain information about constituent structure, then morpheme boundaries for these items would be absent in the speech plan.

The finding that the assimilated fake geminates in English, like true geminates, are longer than singletons in both absolute and relative terms can be interpreted to suggest either (1) that the different representations of true and fake geminates cannot be phonetically distinguished or (2) that, like true geminates, assimilated fake geminates are intrinsically long consonants. Whereas a Lexical Phonology framework encourages the first interpretation, whole word and dual route models of lexical access allow for the second.

In Lexical Phonology, words are always accessed via their constituent morphemes. Assimilated fake geminates are therefore seen as arising in English when the final sound of a level 1 prefix is assimilated, and so made identical to, the initial sound of the root to which it is attached. Once the morpheme boundary is deleted from the representation following the assimilation process, there may be no way to phonetically distinguish between length due to the production of a consonant sequence and length due to a single long consonant. At least in the current study, we assumed that the only way to establish a phonetic distinction between the two types of representation is by exploiting the possibility that a boundary is or is not represented in the speech plan.

In contrast to Lexical Phonology, whole word and dual route models of lexical access might be interpreted to support a view in which fake geminates are represented in the same way as true geminates; namely, as a single long consonant. This suggestion follows from the proposal that multimorphemic lexical items are either accessed directly (whole word models) or accessed following either a whole-route or decomposed route (dual route models), which means that lexical items are represented both as whole items and as decomposed items. If we make the further assumption that holistic representations do not make reference to constituent structure, and encode the phonological and phonetic information necessary for accurate production, then we might conclude that a long sound (i.e., fake geminates) may be straightforwardly represented in holistic representations as a segment with intrinsic length.

Fowler (1980) was an early advocate for the view that temporal information is an intrinsic part of speech sound representation in all languages—a view that was formalized by Browman and Goldstein in Articulatory Phonology (Browman & Goldstein, 1986, 1990, 1992) and is actively advocated for in the phonetics literature. In Articulatory Phonology, phonological representations are based on linguistically relevant vocal tract constrictions, referred to as gestures. The phonological specification of a lexical item is the pattern of relative timing of gestures corresponding to the sequencing and allophonic realization of the target sound pattern. These patterns are known as gestural scores, and every lexical entry is presumably associated with its own gestural score.

Gestural scores provide a straightforward specification of articulatory movement, which can be used to build speech plans. So let's take the case of words with singleton and fake geminate consonants, such as *immensely* and *immoral*. The gestural scores for these words differ not only in the patterns associated with the second and third syllables, but also in the relative timing of their similar initial vowel-nasal-vowel sequences. The tongue body gesture associated with the second vowel would be phased later with respect to the bilabial and velic gestures associated with the /m/ in *immoral* relative to the /m/ in *immensely*. Again, such information would be part of the lexical representation; a suggestion that seems compatible with the notion of holistic representation in whole word and dual route models of lexical access.

In contrast to the possibility that assimilated fake geminates in English are represented with length just like true geminates, our results strongly suggest that word-boundary fake geminates are represented as consonant sequences. Consider the result that word-boundary fake geminates were only ever longer than matched singletons in absolute terms. The finding that these geminates had the same relative durations as singletons suggests that preceding vowels were lengthened along with the consonants as part of a boundary-dependent lengthening process. Such a suggestion is consistent with the unsurprising finding that word boundary geminates were frequently pulled apart in careful speech via F0 changes and pause insertion. Both findings argue for a representation in which a consonant sequence spans a boundary that is also realized in the speech plan.

The results on concatenated fake geminates are more opaque. Like the assimilated fake geminates in this study, concatenated fake geminates were also longer than singletons in absolute and relative terms. The concatenated fake geminates of *un*- prefixed words nonetheless differed from the assimilated fake geminates in *in*- prefixed words in two respects: the absolute duration of the /n/ in *un*- prefixed words was longer than the absolute duration /m/ in *in*- prefixed words. And, more intriguingly, speakers marked the morpheme boundary between the *un*- prefix and root in careful speech via F0 changes and occasionally via pause insertion.

The finding that concatenated fake geminates behaved very similarly to assimilated fake geminates in normal speech, but more like word boundary fake geminates in careful speech, could indicate that *un*-prefixed words are sometimes represented with a morpheme boundary in the speech plan and sometimes without one. Whereas Lexical Phonology and whole word models of lexical access do not allow for different representations of the same class of words, dual route models of lexical access do.

The longer absolute duration of the concatenated fake geminates compared to the assimilated fake geminates was likely due specifically to the morpheme *un*- rather than to intrinsic differences in the duration of /n/ and /m/. Like Hay (2002, 2007), we assume that the durational differences mark differences in affix semantic transparency and productivity, which in turn may suggest differences in how words with such affixes are accessed. Whereas words with level 1 prefixes may be preferentially accessed as whole items, words with level 2 prefixes may be preferentially accessed via their constituent morphemes, especially when the lexical frequency of the base is high relative to the frequency of the whole word. A word that is accessed in a decomposed form will likely also have a segmented form representation. Thus, fake geminates that arise at a morpheme boundary in words and are accessed in a decomposed form may be represented as a consonant sequence, just like word boundary geminates. When this happens, concatenated fake geminates will behave more like word boundary geminates than like assimilated fake geminates. In the present study, this happened only in the careful speaking condition.

Under normal speaking conditions, the concatenated fake geminates behaved almost exactly like the assimilated fake geminates in the present study. Although the *un*- prefixed words with fake geminates may be preferentially accessed in decomposed form, it is conceivable that speakers in the present study would have defaulted to accessing the whole forms of these words for two reasons. First, all stimuli were repeated several times over the course of the experiment. This repetition would have boosted the frequency with which the stimulus words were accessed, which would have facilitated whole route access. Secondly, the stimulus set did not include items that would have encouraged the semantic decomposition of any of the prefixed words, nor did the frame sentences support the compositional semantics of the target words. For these reasons, we conclude that the similar behavior of concatenated and assimilated fake geminates in this study suggests similar representations in the speech plan.

5. Conclusion

Although English fake geminates are not phonemic, those that occurred in prefixed words had longer absolute and relative durations that those that occurred across a word boundary. With few exceptions, prefixed words were also produced without boundary cues, in contrast to two word phrases where the boundary was regularly identified via F0 changes and pause insertion in careful speech and often identified in the same way in normal speech. Assuming a dual-route model of lexical access and lexical-phonological representations of the sort proposed in Articulatory Phonology, the results suggest that word-internal fake geminates, and especially assimilated fake geminates, are represented and accessed as long consonants in English. Only fake geminates in two word phrases exhibit phonetic characteristics that are wholly consistent with the representation of a consonant sequence.

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Table 1. Word-internal singletons and word boundary geminates were chosen to match words with word-internal assimilated and concatenated fake geminates. The table shows the stimulus set and the phonetic transcription of the target words.

Word-internal singletons	**Word-internal geminates**	**Word boundary geminates**
ammonia [əmo□nyə]	immoveable [□muv□b□l]	dim morning [d□m m□rniŋ]
immensely [□m□nsli]	immoral [□m□r□l]	grim magic [gr□m mæ□□k]
immunity [□myun□ti]	immemorial [□m□m□ri□l]	prim memorial [pr□m m□m□ri□l]
immigrational [□m□gre□□ən□l]		slim moviedom [sl□m muvid□m]
annex [□n□ks]	immeasured [□mm□□□rd]	one nail [w□n ne□l]
innate [□ne□t]	unnoticed [□nno□t□st]	fun name [f□n ne□m]
annoyed [□n□□d]	unnamed [□nne□md]	fun noise [f□n n□□z]
innerve [□n□rv]	unnerve [□nn□rv]	one nurse [w□n n□rs]
	unnail [□nne□l]	

Table 2. The mean frequency of the base morpheme was divided by the mean frequency of the whole word. These values are shown here for the target words containing word-internal singletons, word-internal geminates and word boundary geminates.

Word-internal singletons	**Word-internal geminates**	**Word boundary geminates**
ammonia (0)	immovable (0.02)	dim morning (1)
immensely (0)	immoral (0.11)	grim magic (1)
immunity (0)	immemorial (0.55)	prim memorial (1)
immigrational (0.5)	immeasured (1)	slim moviedom (1)
annex (0)	unnoticed (0.09)	one nail (1)
innate (0)	unnamed (0.24)	fun name (1)
annoyed (0)	unnerve (0.9)	fun noise (1)
innerve (1)	unnail (1)	one nurse (1)

Table 3. Mixed-effect of consonant types on absolute consonant duration in normal, careful speaking style and the difference between normal and careful speaking style. Speaker and item were included as random factors.

	Normal				Careful				Careful-Normal			
	Coefficient	SE	t	Pr(>|t|)	Coefficient	SE	t	Pr(>|t|)	Coefficient	SE	t	Pr(>|t|)
Intercept	147.55	10.98	13.44	0.000	208.44	8.50	24.52	0.00	86.38	6.12	14.11	0.00
wrd-int gem v. singleton	-56.99	14.29	-3.99	0.001	-89.78	9.77	-9.19	0.00	-49.38	6.97	-7.09	0.00
wrd-int gem v. wrd bndry gem	8.99	14.29	0.63	0.529	18.01	7.77	1.84	0.07	9.98	6.97	1.43	0.15

Table 4. Mixed-effect of consonant types on relative consonant duration in normal, careful speaking style and the difference between normal and careful speaking style. Speaker and item were included as random factors.

	Normal				Careful				Careful-Normal			
	Coefficient	SE	t	Pr(>|t|)	Coefficient	SE	t	Pr(>|t|)	Coefficient	SE	t	Pr(>|t|)
Intercept	1.88	0.064	29.42	0	2.065	0.097	21.315	0	0.227	0.069	3.266	0.0012
wrd-int gem v.singleton	-0.53	0.088	-6.00	0	-0.630	0.127	-4.976	0	-0.238	0.076	-3.142	0.0018
wrd-int gem v. wrd bndry gem	-0.53	0.088	-5.95	0	-0.605	0.127	-4.772	0	-0.188	0.076	-2.484	0.0133

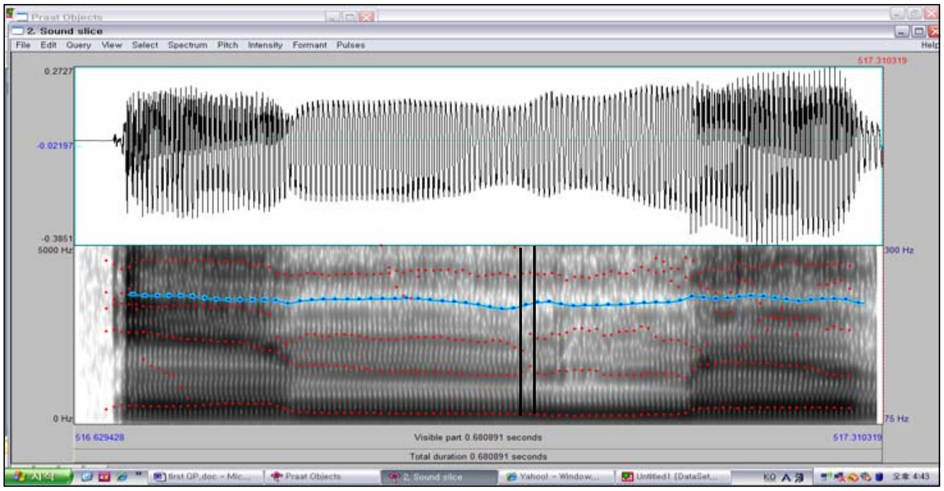

Figure 1. Syllable offset and onset measures were taken on either side of a syllable boundary, which was defined either by a pause, a discontinuity in the waveform (shown here), or at the midpoint of the nasal. The example VCCV sequence shown here is from the word *immovable*.

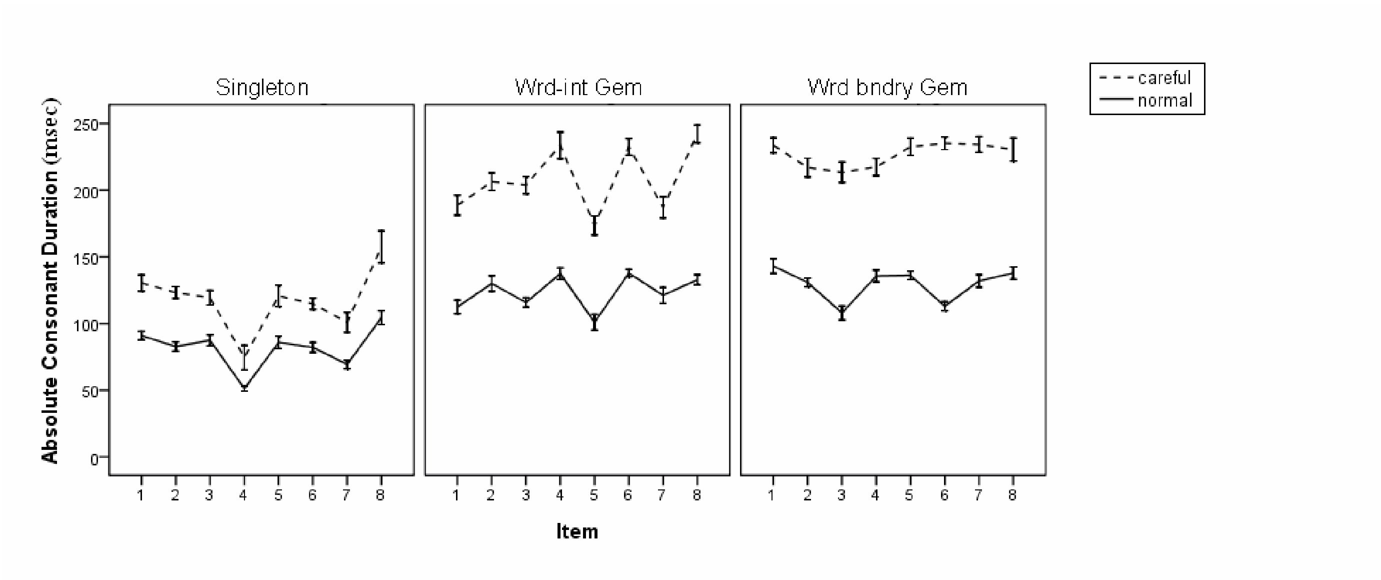

Figure 2. Absolute consonant duration is shown for each item within each consonant type (word-internal singletons, word-internal geminates, word boundary geminates) produced in normal and careful speech.

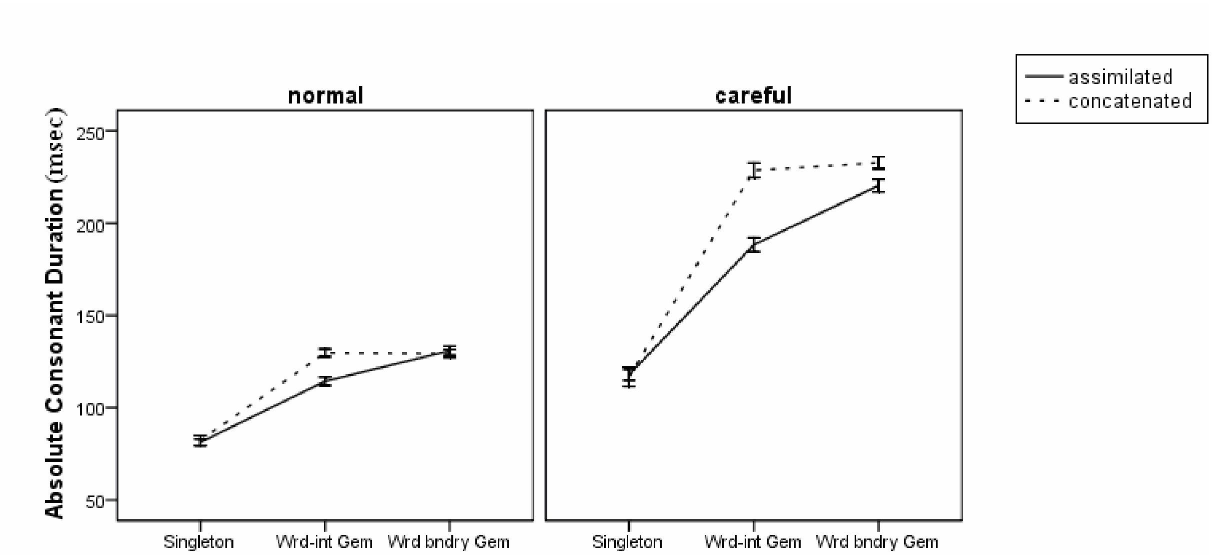

Figure 3. Absolute consonant duration is shown for word-internal singletons, word-internal assimilated, concatenated geminates and word boundary geminates produced in normal and careful speech.

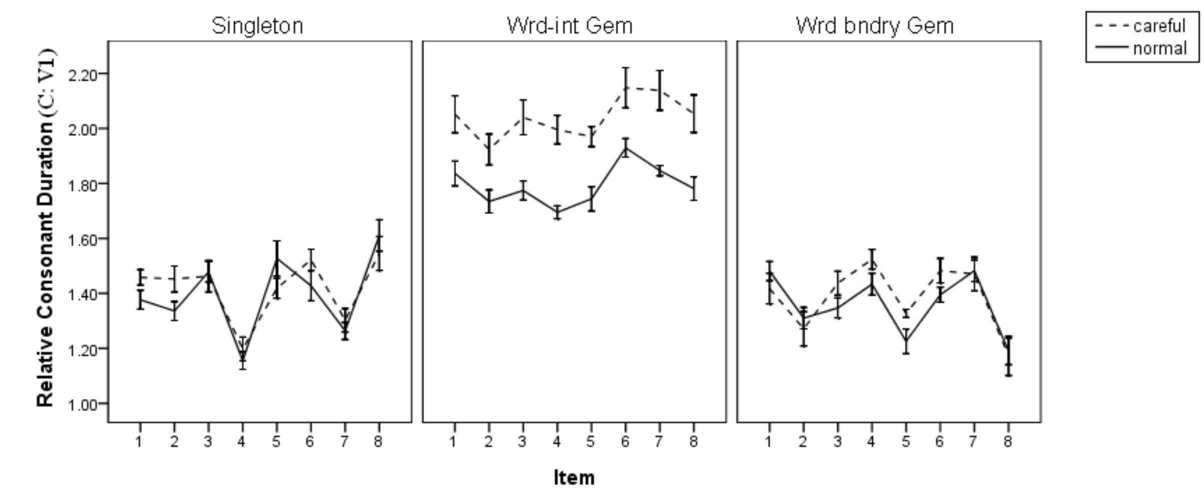

Figure 4. Relative consonant duration is shown for each item within each consonant type (singleton, word-internal geminate, word boundary geminate) produced in normal and careful speech.

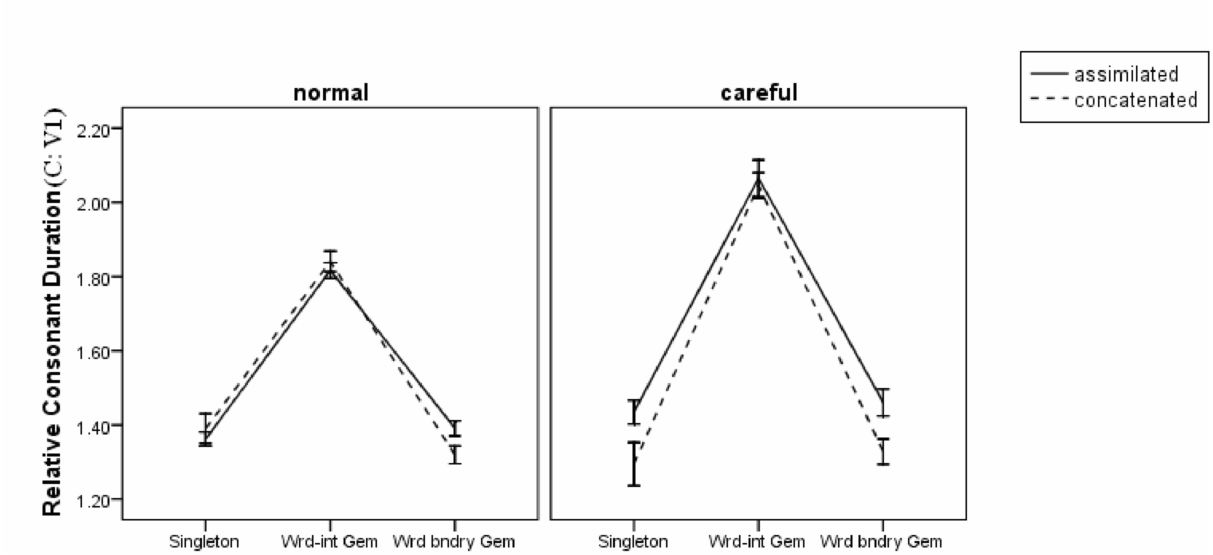

Figure 5. Relative consonant duration is shown for word-internal singletons, word-internal assimilated, concatenated geminates and word boundary geminates produced in normal and careful speech.

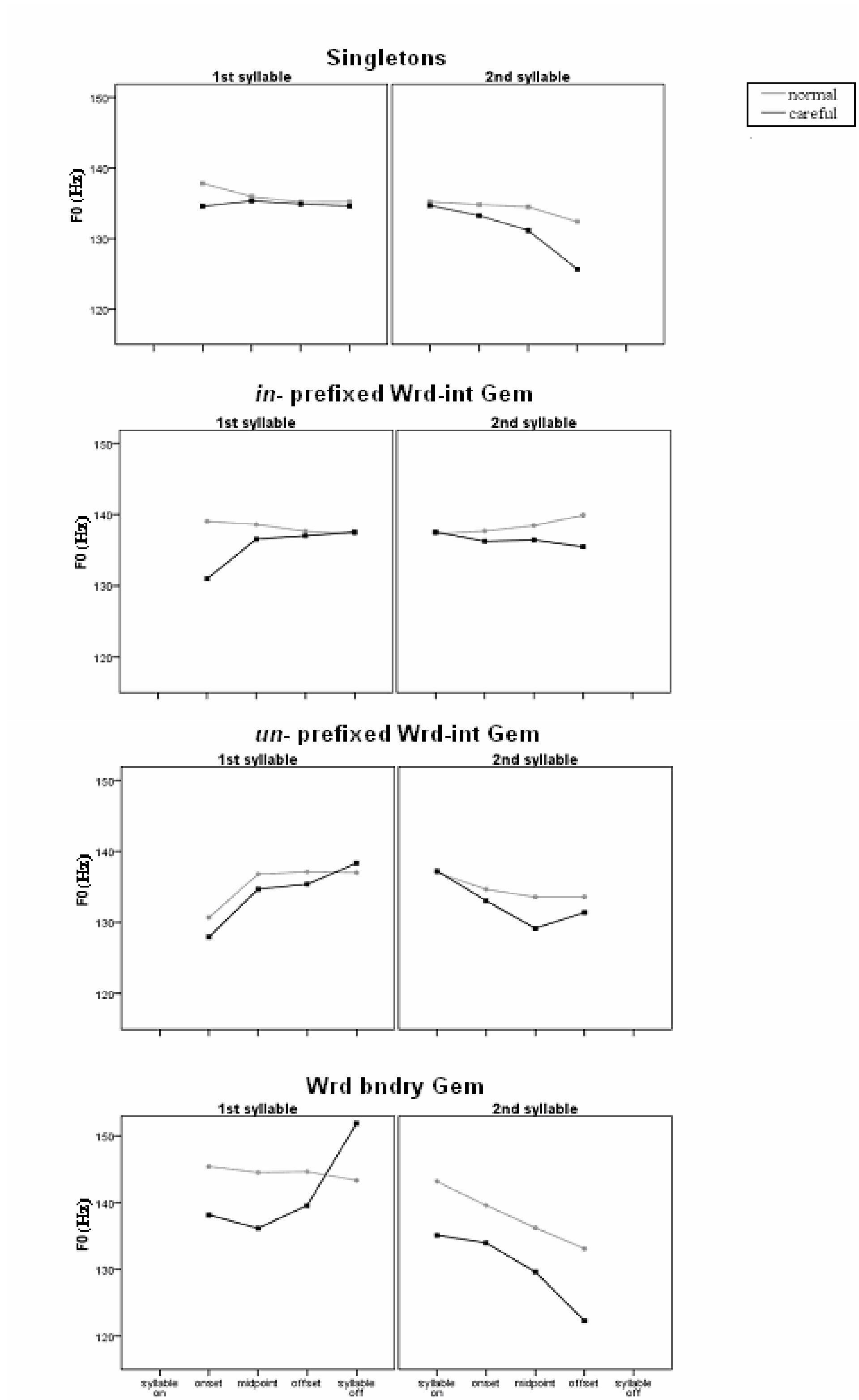

Figure 6. F0 measures at V1 onset, midpoint, offset, and syllable offset followed by F0 measures at syllable onset, V2 onset, midpoint, offset are shown to describe the intonation contours of word-internal singletons, word-internal assimilated, concatenated geminates, and word boundary geminates produced in normal and careful speech.