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Effect of Stress on the Realization of Plosives in New Zealand English

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Abstract
This study provides a more comprehensive examination of the three voiceless plosives /p, t, k/ in New Zealand English (NZE) than previous literature. More specifically, the current study explores the lenition of word-medial plosives to fricated variants, and the degree of aspiration of word-medial plosives. Our focus on different stress positions allows us to address an additional theoretical issue concerning prosodic categories in English. Two types of vowels (reduced vowels and *happ*Y vowels) are usually classified as being in unstressed syllables in English phonology. Using this impressionistic classification of vowels in unstressed syllables as a starting point, acoustic data from lenition and aspiration is analysed to examine the extent to which these two types of vowels pattern in a similar manner, as would be expected if they both occurred in unstressed syllables.

Keywords plosive, stress, aspiration, lenition, New Zealand English

1. Introduction

It is well-known that the phonetic realization of plosives is affected by their prosodic status in English. For instance, in American English, plosives are less aspirated and are more likely to be realized as flaps in unstressed syllables than in stressed syllables (Hayes, 1995, p. 12-13; Warner & Tucker, 2010), and in RP, plosives are likely to be realized as aspirated stops or affricates before stressed vowels but as fricated variants before unstressed vowels (Buizza & Plug, 2012).

The aim of this paper is two-fold. The first is to provide a more comprehensive examination of the three voiceless plosives /p, t, k/ in New Zealand English (NZE) than previous literature. More specifically, the current study explores the lenition of voiceless plosives to fricated variants, and the degree of aspiration of voiceless plosives. The current paper focuses on the context of word-medial position, because this context is known to show a variety of leniting phenomena (Lavoie, 2001). While several studies have looked at the phonetic realizations of plosives in NZE, most have focused on the coronal and limited discussion to the trochaic environment (V́_V̌) (Holmes, 1995; Bauer & Holmes, 1996; Taylor, 1996; Bayard, 1999; Silby, 2008; Fiasson, 2015; Hay & Foulkes, 2016 among others). Hence, less is known about the realization of /t/ in non-trochaic environments and about the realizations of /p, k/ more generally in NZE. The present study contributes to the literature by examining how all three voiceless plosives /p, t, k/ are realized in primary stressed syllables, secondary stressed syllables and unstressed syllables in NZE. Additionally, some variables that are known to affect aspiration and lenition in other varieties of English (e.g., word frequency, surrounding vowel height, preceding vowel length, and gender) are also examined.

Our focus on different stress positions allows us to address an additional theoretical issue concerning prosodic categories in English. As will be reviewed in Section 2.2, two types of vowels (reduced vowels and *happ*Y vowels) are usually classified as being in unstressed syllables in English phonology. Reduced vowels refer to vowels occurring in word-final syllables such as in *cactu̲s* and *manne̲r*, while *happ*Y vowels refer to those in words such as *city̲* and *happy̲* (Wells, 1982). Using this impressionistic classification of vowels in unstressed syllables as a starting point, acoustic data from lenition and aspiration is analysed to examine the extent to which these two types of vowels pattern in a similar manner, as would be expected if they both occurred in unstressed syllables.

This paper is organized in the following way. Section 2 reviews previous literature relating to the topics at hand, and lays out predictions for the realization of plosives. In Section 3, the experimental design is outlined while in Section 4 the results of the experiment are reported. The results are discussed in Section 5, and a summary and general discussion conclude the paper in Section 6.

2. Background

2.1 Lenition and aspiration in English

2.1.1 Prosodic effects on voiceless plosives

The influence of prosody on the phonetic realization of voiceless plosives has been studied in great depth in several varieties of English: RP (Buizza & Plug, 2012); Liverpool English (Honeybone, 2001; 2012); dialects of England and Scotland (Harris, 1994: 196); Australian English (Loakes & McDougall, 2010); American English (Lisker & Abramson, 1967; Hayes, 1995, p. 12-13; Turk, 1992; Lavoie, 2001 among others). The findings can be summarized as follows. In unstressed syllables, voiceless plosives are likely to be flapped, glottalized or spirantized, while they are likely to be pronounced as stopped variants in stressed syllables. As for aspiration, voiceless plosives have a longer release phase (VOT) in stressed syllables than in unstressed syllables. For example, in American English, coronal plosives are flapped in unstressed syllables while they are aspirated in stressed syllables, and labial and dorsal plosives are unaspirated in unstressed syllables whereas they are aspirated in stressed syllables (Hayes, 1995, p. 12-13). Hayes argues that plosives in word-final syllables in *imitate* [íməṯʰeɪt], *maritime* [mǽrəṯʰaɪm] and *proton* [próʊṯʰan] are stopped and aspirated, whereas those of *hockey* [háḵi], *motto* [máɾ̠oʊ] and *campus* [kǽmp̠əs] are unaspirated or flapped. The reason for this difference is, arguably, because the syllables in the former group bear secondary stress while those in the latter are unstressed. In other words, voiceless plosives are less likely to be lenited and more likely to be aspirated in stressed syllables than in unstressed syllables. Previous research also points out that plosives occurring in primary- and secondarily stressed syllables can differ with regards to lenition: in primary stressed syllables, lenition is less likely to occur (Eddington & Elzinga, 2008), and the duration of plosives is longer (Crystal & House, 1988; Turk & Sawusch, 1997; Turk & White, 1999).

As for NZE, while several studies have looked at the phonetic realization of voiceless plosives, as noted above, the findings are largely restricted to coronal plosives in a trochaic environment V́_V̌ (Holmes, 1995; Bauer & Holmes, 1996; Taylor, 1996; Bayard, 1999; Silby, 2008; Fiasson, 2015; Hay & Foulkes, 2016; among others). These studies report that /t/ is likely to be lenited in a trochaic context, being realized as a fricated or flapped variant. The phonetic realization varies as a function of speech style. In word-list reading, /t/ tends to be fricated, with this tendency being stronger in female and younger speakers (Taylor, 1996; Fiasson, 2015, p. 48). Further, /t/ is rarely flapped in a word-list reading task (Taylor, 1996; Silby, 2008; Fiasson, 2015, p. 57). On the other hand, in spontaneous speech, /t/ may be pronounced as a flap. Social factors (e.g. age, gender, and social class) also influence the realization of /t/ as a fricated or flapped variant in spontaneous speech. The studies cited above show that /t/ is more fricated in older, female and professional speech, whereas /t/ is more likely to be flapped in younger, male and non-professional speech. The realization of NZE /t/ in trochaic environments has thus been well-studied, while in non-trochaic environments discussion is limited (but see Holmes, 1994). The literature is also sparse regarding the other two NZE plosives /p/ and /k/. Bauer and Warren (2004; 2007) and Bauer et al. (2007) hypothesize that /p/ is aspirated and /k/ is affricated in an initial stressed syllable, and speculate that they may be aspirated intervocalically in stressed syllables. The current study tests these hypotheses by providing a more comprehensive examination of three voiceless plosives /p, t, k/ in main-stressed, secondary-stressed, and unstressed word-medial syllables.

2.1.2 Other effects on voiceless plosives

Although the main aim of this study is to examine the influence of stress on voiceless plosives, we take note that the following factors may also affect their phonetic realization: gender, lexical frequency, place of articulation, surrounding vowel height, and preceding vowel length. Although these factors are discussed in other varieties of English or other languages, most have not been explored in NZE. In addition to prosodic positions, these variables will also be examined in the statistical analyses of lenition (Section 4.1) and aspiration (Section 4.2).

As was noted in 2.2.1, gender may affect the phonetic realization of coronal voiceless plosives in NZE. Previous literature (Taylor, 1996; Fiasson, 2015) finds that female speakers pronounce more fricated variants in wordlist speech than male speakers in NZE.

The effect of lexical frequency on plosive realization is contradictory. Warner and Tucker (2010) examine the phonetic realization of plosives in American English to find that lexical frequency does not have a significant effect on word-medial reduction. On the other hand, word frequency has been found to have an effect in American English (Bouavichith & Davidson, 2013) and NZE (Hay & Foulkes, 2016): lenition of plosives is more likely in higher frequency words. As for consonant duration, both Warner and Tucker (2010) and Bouavichith and Davidson (2013) report that there is no lexical frequency effect.

Place of articulation is well-known to affect the phonetic realization. Lavoie (2001, p. 133) and Bouavichith and Davidson (2013) show that bilabial plosives are most likely to be realized as plosives in American English, coronal plosives are least likely, and dorsal plosives are in between (Loakes & McDougall, 2010). As for VOT, Lisker and Abramson (1967) find that it is shortest for bilabial plosives, and it is longest for dorsal plosives in American English.

The effect of local vowel context has been discussed by several studies. The effect of surrounding vowel height is contradictory. Kirchner (2001) argues that lenition occurs in the context of more open vowels, whereas Kingston (2008) argues that vowel height does not affect lenition rates. The effect of preceding vowel length is discussed in Bérces and Honeybone (2012), who argue that lenition is more likely to occur after stressed short vowels in some languages. Although Bye and de Lacy (2008) impressionistically generalize that flapping occurs only after a stressed short vowel in the formal register of NZE, the detail has not been explored. Lisker and Abramson (1967) find that vocalic environments do not affect VOT in American English, while Klatt (1975) reports that plosives are more aspirated before high vowels.

2.2 Stress in English

A central assumption underlying the findings above is that the classification of stressed syllables in NZE is the same as in the other varieties of English reported. This study tests this assumption using evidence from the effect of stress on NZE plosives.

Generally speaking, stress in English varieties is typically defined in terms of one of three properties: pitch level, prominence over neighbouring syllables in quantity and/or loudness, and vowel quality (Kenyon & Knott, 1944; Gimson, 1970; Liberman & Prince, 1977; Bauer et al., 1980; Fudge, 1984; Halle & Vergnaud, 1987; Kager, 1989; Pater, 1995; Schane, 2003, 2007; among others). A vowel is considered to be in a primary stressed syllable, if (1) the vowel is full, as opposed to reduced, (2) the syllable can be pitch-accented, and (3) the syllable is more prominent than neighbouring syllables. A vowel is in a secondary stressed syllable if it satisfies the first or second of the three criteria[2]: a vowel is deemed unstressed if it satisfies none of the criteria. That is, a syllable with a reduced vowel is always in an unstressed syllable, while a syllable with a full vowel has some degree of stress in English (see Schane, 2003). For example, in the Canadian English variety spoken by the second author, the word *anticipate* [æ̀ntísəpèɪt] consists of three stressed syllables and one unstressed syllable, because the first two syllables and the final syllable have full vowels and the penultimate syllable has a reduced vowel. As for the morphologically derived form *anticipation* [æ̀ntìsəpéɪʃən], the first two syllables and the penultimate syllable are stressed, while the antepenultimate and final syllables are unstressed. Despite this definition, some phonological studies assume that word-final tense vowels /i, oʊ/ are also unstressed, for example, *ci<u>ty</u>*, *fan<u>cy</u>*, *hoc<u>key</u>*, *mot<u>to</u>*, *Os<u>lo</u>*, and *toma<u>to</u>* (Chomsky & Halle, 1968[3]; Halle & Keyser, 1971; Hayes, 1995; Hammond, 1999 among others). Hayes (1995, p. 9–21), for example, offers the following taxonomy of stressed vowels and unstressed vowels:

(1) Taxonomy of vowels in stressed and unstressed syllables in American English[4]

a. Never stressed: [ə, n̩, m̩]
b. Variable: [i, oʊ]: unstressed in word-final and pre-vocalic positions; otherwise stressed
[ɪ]: unstressed before /ŋ/; otherwise stressed
c. Always stressed: [eɪ, ɛ, æ, a, ɔ, ʌ, ʊ, u]

Although the studies cited above concern American English, Bauer (1986) and Bauer and Warren (2004; 2007) assume a similar classification for NZE vowels: that is, as shown in (2), reduced vowels are always unstressed, full vowels have a certain degree of stress, and word-final /i/ can be unstressed:

(2) Taxonomy of stressed and unstressed vowels in NZE

a. Never stressed: [ə]
b. Variable [i]: unstressed in word-final positions; otherwise stressed
c. Always stressed: [ɪ, e, æ, ʌ, ɒ, ʊ, a, ɔ, u, ɜ, iə, eə, ei, aʊ, oʊ, ai, ɔi, ʊə]

By studying the effects of stress on the lenition and aspiration of plosives in NZE, the current study is able to test the vowel taxonomy in (2). Reduced and *happ*Y vowels are of particular interest since both are assumed to occur in unstressed syllables, despite the vowel in *happ*Y being a full vowel.[5] We lay out the relevant predictions just below.

2.3 Predictions

Based on previous studies regarding stress, lenition and aspiration in NZE and other varieties of English, we can begin with two general assumptions. First, there is a hierarchy in syllable prominence in English: primary stressed > secondary stressed > unstressed (headed by reduced vowels or *happ*Y vowels). Second, lenition and aspiration are influenced by syllable stress. Based on this, we offer the following predictions regarding NZE:

(3) Predictions

a. The degree to which a plosive is aspirated in NZE is correlated with the degree of stress on the syllable, measured in terms of mean VOT of plosive.

b. The degree to which a plosive is lenited (i.e. pronounced as a fricated or flapped variant) is inversely correlated with the degree of stress on the syllable, measured in terms of the number of lenited variants produced.

c. Reduced vowels and *happ*Y vowels occur in unstressed syllables and thus influence plosives with regards to lenition and aspiration in a similar manner.

Note that 'primary stressed syllables' are always 'intonationally pitch-accented syllables' in the current study due to the experimental design, which is explained in the following section. This point will be discussed at the end of 5.1.

3. Research design

3.1 Subjects

Seven male and seven female speakers of NZE, aged between 19 and 27, participated in this study. All the participants are monolingual NZE speakers, but three speakers reported that they have studied Japanese but are not fluent. All subjects were recruited at the University of Canterbury and through websites.

3.2 Procedure and Material

All participants were invited individually to a sound booth at the University of Canterbury. They pronounced three repetitions of 120 words containing intervocalic voiceless plosives within a carrier sentence 'Say __ please.' The stimuli were presented in random order, using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Their pronunciation was recorded using a Tascam HD-P2 audio recorder.

The words were obtained from CELEX (Baayen et al., 1995) with their NZE pronunciations subsequently checked using *The New Zealand Oxford Dictionary* (Deverson & Kennedy, 2005). The collected words, as given in (4), were divided into four groups based on the final syllable of the word: (a) plosive + primary stressed vowel; (b) plosive + secondary stressed vowel; (c) plosive + reduced vowel; (d) plosive + *happ*Y vowel. Each group consists of 30 words with bilabial, coronal, and dorsal plosives occurring in 10 words each.

(4) Word-list[6]

- (a) XPV́(C)#: apart, appeal, depart, depose, oppose, prepare, propose, repair, repeat, superb, atone, attach, attain, cartoon, curtail, deter, eighteen, guitar, return, tattoo, accord, account, akin, arcade, become, decode, locate, occur, raccoon, recall
- (b) XPV̀(C)#: anthropoid, apex, bypass, coupon, dissipate, epoch, occupy, propane, stipend, tripod, appetite, cortex, detail, fertile, futile, imitate, leotard, proton, protein, retail, allocate, archive, bicarb, decade, decoy, educate, forecast, icon, indicate, teacup
- (c) XPə(C)#: copper, corpus, deepen, happen, open, paper, purpose, sharpen, upper, weapon, atom, autumn, beta, bottom, butter, cheetah, data, item, matter, status, baker, bacon, beacon, blacken, caucus, circus, focus, locust, poker, waken
- (d) XPi#: copy, creepy, happy, harpy, hippie, nappy, puppy, sleepy, sloppy, weepy, arty, beauty, city, dirty, eighty, forty, hearty, mighty, party, pretty, cookie, creaky, jockey, lucky, rocky, shaky, spiky, sticky, tricky, turkey

Three criteria were used to select the words: (i) segmental position of the plosive, (ii) number of syllables, and (iii) degree of familiarity. As for the first criterion, target plosives occur intervocalically preceding word-final vowels in all words. With respect to syllable count, most words are disyllabic. Although an attempt was made to use only disyllabic words, group (b) contains nine trisyllabic words (*allocate*, *anthropoid*, *appetite*, *dissipate*, *educate*, *imitate*, *indicate*, *leotard*, *occupy*) since disyllabic words with the needed patterns are uncommon. An attempt was also made to collect words that are familiar to native speakers in order to encourage natural speech in the recording. All the words are supposed to have a certain degree of familiarity, as they were checked by NZE speakers before the experiment.

A total of 5,040 tokens were recorded, although 180 tokens (3.6%) were eliminated due to mispronunciation, leaving a dataset of 4,860 tokens for analysis.

3.3 Acoustic analysis

Acoustic analyses of the three voiceless plosives /p, t, k/ were conducted using Praat (Boersma & Weenink, 2016). As for their allophonic realization, the current study follows Fiasson (2015, p. 45), and the plosives were classified as either a stopped, fricated, or flapped variant in the following way. A token is regarded as a stopped variant, if it has a silent gap representing an articulatory closure.[7] A token is identified as a fricated variant, if it has only aperiodic noise throughout the consonantal domain. A token is labelled as a flapped variant, if it retains a formant structure throughout the consonantal domain. In order to improve the reliability of labelling, the first author and the second author discussed the annotation together, and we asked some other phoneticians to check our annotation at the beginning of our analysis. In fact, there were not so many ambiguous tokens because of the criteria employed by Fiasson (2015), as closure phases are always clear. The sample tokens are shown in Figure 1.

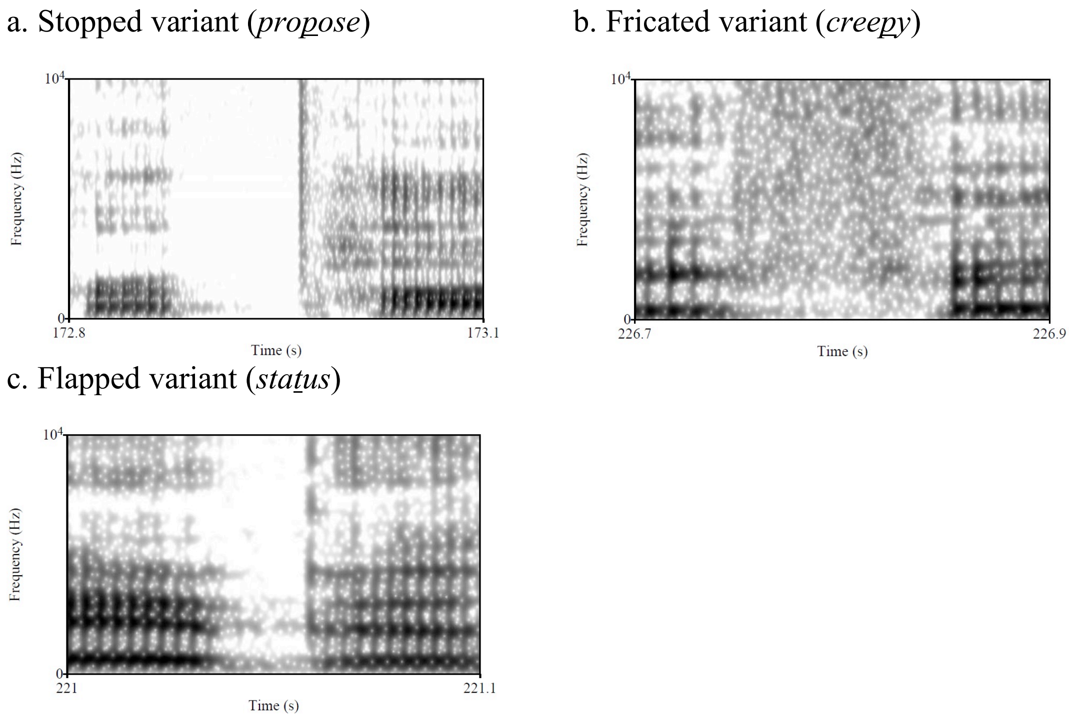

Figure 1: Sample annotation of three variants

One of the reviewers asked us what kind of sounds *fricated plosives* are. Loakes and McDougall (2010) demonstrate that fricated /t/ is acoustically close to /ʃ/ but shorter than this phonemic fricative in Australian English. However, it is still an open question exactly what kind of acoustic and articulatory properties fricated plosives have. In the current study, fricated plosives refer to variants without closure phases and with only aperiodic noise, and their exact phonetic properties are beyond the scope of this study. *Fricated variants* are used rather than *fricatives* on purpose throughout the current paper to distinguish them from inherent fricatives such as /s/ and /ʃ/.

For those identified as stopped variants, the duration of their release (VOT) phase was measured, that is, the period between the release burst and the onset of voicing in the following vowel. Of 3,611 tokens identified as stopped variants, 192 (5.3%) did not have a visible burst and consequently VOT was not measured for those tokens. As is shown in Figure 2, the left-hand token has a clear vertical line that indicates the release burst, while the right-hand one has no clear line.

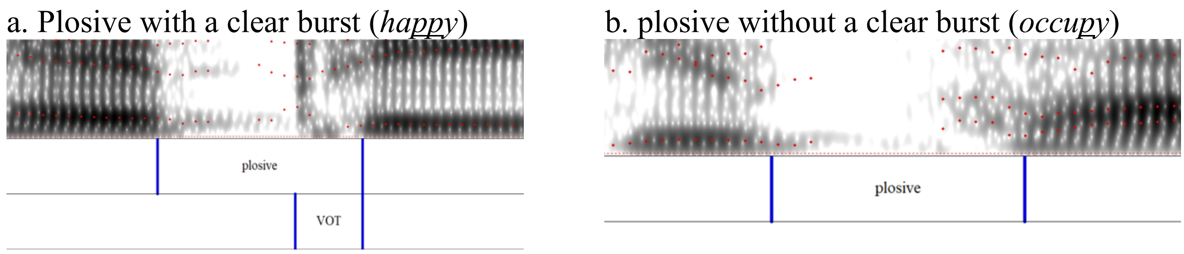

Figure 2: Sample annotation of VOT

4. Results

4.1 Lenition

This section explores the relation between the plosive's allophonic realization (stopped, fricated, and flapped variants) and prosodic position (primary stressed syllables, secondary stressed syllables, unstressed syllables headed by reduced vowels or *happ*Y vowels). Flapped variants are excluded from statistical analysis because few tokens (0.3%) were produced in the word-list reading context, as shown in Table 1. This finding is consistent with previous studies on NZE coronal plosives (Taylor, 1996; Silby, 2008; Fiasson, 2015), which found that few plosive phonemes are realized as flaps in a word-list reading. Table 1 provides the number and percentage of each allophonic pattern in terms of its prosodic position and consonant place.[8]

Table 1: Allophonic realization of /p, t, k/ according to syllable stress

a. Bilabial plosive

	Xp̱V́(C)#	Xp̱V̀(C)#	Xp̱ə(C)#	Xp̱i#	SUM
stopped	404 (99%)	345 (92%)	324 (77.7%)	338 (80.5%)	1,411 (87.1%)
fricated	4 (1%)	30 (8%)	93 (22.3%)	82 (19.5%)	209 (12.9%)
Total	408	375	417	420	1,620

b. Coronal plosive

	XṯV́(C)#	XṯV̀(C)#	Xṯə(C)#	Xṯi#	SUM
stopped	356 (90.6%)	260 (63.2%)	138 (33%)	176 (42.3%)	930 (56.8%)
fricated	37 (9.4%)	150 (36.4%)	271 (64.8%)	236 (56.7%)	694 (42.4%)
flapped	0 (0%)	1 (0.4%)	9 (2.2%)	4 (1%)	14 (0.8%)
Total	393	411	418	416	1,638

c. Dorsal plosive

	XḵV́(C)#	XḵV̀(C)#	Xḵə(C)#	Xḵi#	SUM
stopped	363 (97%)	334 (83.1%)	294 (72.1%)	279 (66.7%)	1,270 (79.3%)
fricated	11 (3%)	68 (16.9%)	114 (27.9%)	139 (33.3%)	332 (20.7%)
Total	374	402	408	418	1,602

d. Total

	XP̱V́(C)#	XP̱V̀(C)#	XP̱ə(C)#	XP̱i#	SUM
stopped	1,123 (95.6%)	939 (79%)	756 (60.8%)	793 (63.2%)	3,611 (74.3%)
fricated	52 (4.4%)	248 (20.9%)	478 (38.5%)	457 (36.5%)	1,235 (25.4%)
flapped	0 (0%)	1 (0.1%)	9 (0.7%)	4 (0.3%)	14 (0.3%)
Total	1,175	1,188	1,243	1,254	4,860

Statistical analyses were performed using a binominal mixed effects model with the *glmer* function in the *lme4* library (Bates et al., 2015) implemented in R (R Core Team 2016). The dependent variable, allophonic realization, with two levels 'fricated' and 'stopped' was encoded as a dummy variable with the possible values 0 and 1. The independent variable was prosodic position: a four-level variable coded as: (a) unstressed with reduced vowel (`Syl_unst(@)`); (b) unstressed with happY vowel (`Syl_unst(i)`); (c) secondary stressed (`Syl_secondary`); and (d) primary stressed (`Syl_primary`). The reference level was set as secondary stressed to compare with primary stressed and unstressed. The other variables coded were: consonant place `Cplace` (labial, coronal, dorsal), gender `GENDER` (male, female), preceding vowel height `PrecVheight` (high vowel, non-high vowel), preceding vowel length `PrecV` (phonetically short lax vowel, phonetically long vowel, i.e. tense vowel or diphthong), and log-transformed lexical frequency `LOGFREQ` (continuous variable obtained from CELEX, Baayen et al., 1995).[9] The effect of following vowel height was examined only in a subset of the data which included primary and secondary stressed syllables; since all unstressed syllables headed by reduced or *happ*Y vowels have non-high vowels and high vowels, respectively, their inclusion may have posed a problem of collinearity. Two random intercepts SPEAKER (14 levels) and WORD (120 levels) were added to our models, which account for the variability across the 14 subjects and across the 120 words respectively. In addition, by-speaker random slopes for prosodic positions were added.

In all, 4,860 tokens were hand fit into the regression model with the bobyqa optimizer (Powell, 2009). A comparison of the model with and without preceding vowel height showed that they were not significantly different ($\chi^2(1)=0.019$, $p=0.88$). Models with the interaction of preceding vowel height with other factors were also examined; models without them were selected by ANOVA. Thus, the best-fit model does not include preceding vowel height as a predictor. The model is shown in Table 2. The reference levels are `Syl_secondary`, `Cplace_dor`, `PrecV_long`, and `GENDER_female`.

Table 2: Summary of best-fit model for allophonic realization

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	3.3853	0.6205	5.456	4.86e-08	***
Syl_unst(@)	-0.7739	0.3574	-2.165	0.030378	*
Syl_unst(i)	-1.2809	0.3427	-3.737	0.000186	***
Syl_primary	1.5686	0.5268	2.978	0.002904	**
Cplace_lab	0.8915	0.2379	3.747	0.000179	***
Cplace_cor	-1.4352	0.2340	-6.133	8.65e-10	***
PrecV_short	0.9588	0.4528	2.117	0.034223	*
LOGFREQ	-0.2679	0.1355	-1.977	0.048007	*
GENDER_male	-1.4685	0.6753	-2.175	0.029656	*
Syl_unst(@):PrecV_short	-1.4054	0.5791	-2.427	0.015237	*
Syl_unst(i):PrecV_short	-0.2533	0.5542	-0.457	0.647678	
Syl_primary:PrecV_short	0.9708	0.6772	1.433	0.151722	

As was noted above, positive slopes mean more stopped variants and negative slopes mean more fricated variants, as a stopped variant is assigned a dummy variable of 1. Our predictions in (3) are confirmed. As expected, more stopped variants occur in primary stressed syllables ($\beta=1.56$, $z=2.97$, $p<0.01$) than in secondary stressed syllables, and more fricated variants occur in unstressed syllables headed by reduced vowels ($\beta=-0.77$, $z=-2.16$, $p<0.05$) and *happ*Y vowels ($\beta=-1.28$, $z=-3.73$, $p<0.001$) as compared to in secondary stressed syllables. Further, there is no significant difference between the two types of vowels, that is, reduced and *happ*Y vowels (β=−0.50, z=−1.5, p=0.13) when the reference level of prosodic position (`syl`) was changed to `unst(@)` and the model was rerun. Since there is no significant interaction between prosodic position and consonant place, the magnitude of effects is consistent across the three plosives and the four prosodic positions.

Some other variables were also found to have significant effects. There are main effects of consonant place, preceding vowel length, lexical frequency and gender, while surrounding vowel height was not significant. With respect to consonant place, in comparison to /k/ there are less fricated productions for /p/ (β=0.89, z=3.74, $p<0.001$), and more fricated productions for /t/ (β=−1.43, z=−6.13, $p<0.001$). For preceding vowel length, there are more stopped variants when the preceding vowel is short (β=0.95, z=2.11, $p<0.05$) than when it is long. Further, higher lexical frequency is associated with more lenition (β=−0.26, z=−1.97, $p<0.05$). In terms of gender, there are more fricated variants in male speech (β=−1.46, z=−2.17, $p<0.05$) than in female speech.

In addition, a significant interaction between prosodic position and preceding vowel length was found: as shown in Figure 3, there is more lenition after short vowels than after long vowels but only in unstressed syllables with reduced vowels (β=−1.4, z=−2.42, $p<0.05$). Unstressed syllables with *happ*Y vowels pattern with stressed syllables: there is less lenition after long vowels.

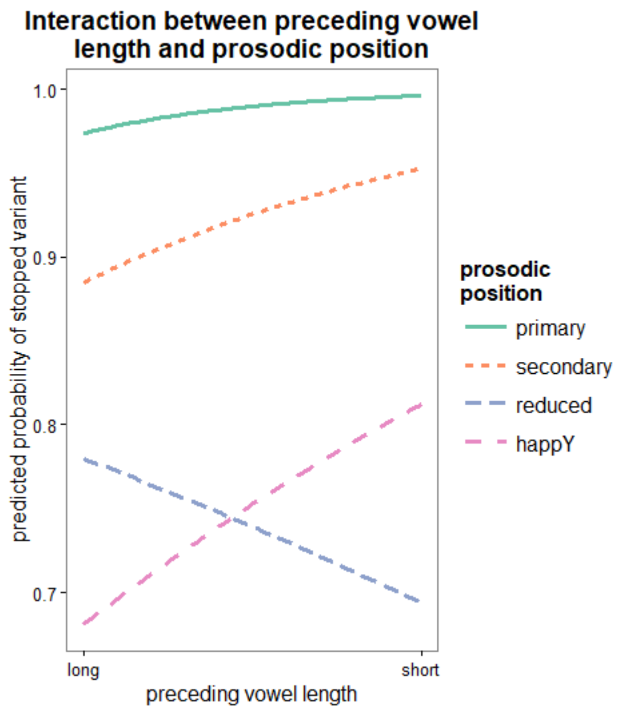

Figure 3: Interaction of preceding vowel length and prosodic positions

The above significant effects are summarized in Table 3. X>Y indicates that more stopped variants are observed given a condition X than given a condition Y and the difference is statistically significant ($p<0.05$).

Table 3: Summary table: significant effects on lenition

Prosodic position (`syl`)	Primary > Secondary > Unstressed No significant difference between the two types of unstressed vowels (i.e., reduced and *happ*Y vowels)
Consonant place (`Cplace`)	Labial /p/ > Dorsal /k/ > Coronal /t/
Preceding vowel (`PrecV`)	Short vowel > Long vowel in general Long vowel > Short vowel only when the following vowel is a reduced vowel
Word frequency (`LOGFREQ`)	Low frequent words > High frequent words
Gender (`GENDER`)	Male speakers > Female speakers

4.2 Aspiration

Next, let us explore the relation between the stopped variant's VOT (i.e. degree of aspiration) and prosodic position. Figure 4 illustrates the mean and 95% confidence interval of VOT in terms of its prosodic position and consonant types.

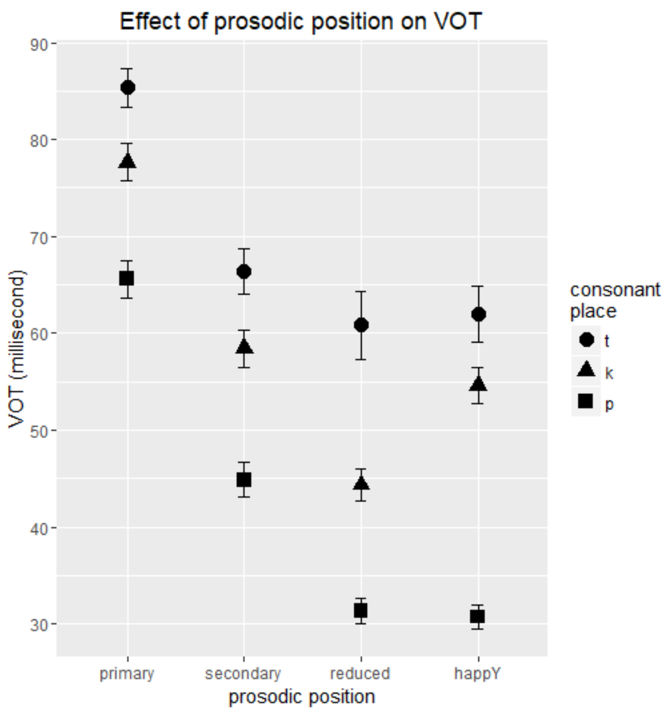

Figure 4: Effect of prosodic position on degree of aspiration of /p, t, k/

With regards to degree of aspiration (VOT) for /p, t, k/, statistical analyses were performed. Backward elimination indicated that lexical frequency does not have a significant effect on the degree of aspiration. A comparison of the model with and without lexical frequency using a linear mixed effects model with the *lmer* function in the *lme4* library (Bates et al., 2015) and *lmerTest* library (Kuznetsova et al., 2016). The dependent variable, VOT, was a continuous variable represented in milliseconds (ms). As with allophonic realization, the effects of several factors were examined: prosodic position (`syl`), consonant place (`Cplace`), lexical frequency (`LOGFREQ`), preceding vowel length (`PrecV`), preceding vowel height (`PrecVheight`), and gender (`GENDER`). The effect of following vowel height (`FolVheight`) is examined in a subset including only primary and secondary stressed syllables. In addition, two random intercepts SPEAKER and WORD, and by-speaker random slopes for prosodic position and consonant place were added to the model.

In all, 3,419 tokens were hand fit into the regression model with the bobyqa optimizer (Powell, 2009). showed that they are not significantly different ($\chi^2(1)=0.56$, $p=0.45$). Models with interactions of lexical frequency with other factors were also examined, but models without them were selected by ANOVA. Hence, lexical frequency was removed from the final model. For the same reason, preceding vowel height ($\chi^2(1)=0.069$, $p=0.79$), preceding vowel length ($\chi^2(1)=1.66$, $p=0.19$) and gender ($\chi^2(1)=0$, $p=0.99$) were also removed. The best-fit model is as in Table 4 with the reference levels being `Syl_secondary` and `Cplace_dor`.

Table 4: Summary of best-fit model for aspiration

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	58.8652	3.3506	17.569	8.88e-16	***
Cplace_lab	-13.8411	2.9075	-4.761	6.92e-06	***
Cplace_cor	5.7515	2.9335	1.961	0.0526	.
Syl_unst(@)	-14.5820	2.7179	-5.365	4.59e-07	***
Syl_unst(i)	-4.9332	2.9323	-1.682	0.0959	.
Syl_primary	18.3456	3.4971	5.246	3.40e-06	***
Cplace_lab:Syl_unst(@)	1.1793	3.6115	0.327	0.7447	
Cplace_cor:Syl_unst(@)	7.2628	3.8033	1.910	0.0584	.
Cplace_lab:Syl_unst(i)	-9.0273	3.6187	-2.495	0.0141	*
Cplace_cor:Syl_unst(i)	0.5991	3.7713	0.159	0.8740	
Cplace_lab:Syl_primary	2.3559	3.5767	0.659	0.5116	
Cplace_cor:Syl_primary	1.2498	3.6388	0.343	0.7319	

Note that positive slopes indicate longer VOT whereas negative slopes indicate shorter VOT. The predictions in (3) are partially supported. First, plosives are more aspirated in primary ($\beta=18.34$, $t=5.24$, $p<0.001$), as opposed to secondary, stressed syllables. No significant interaction is observed between consonant place and primary stress, although there are between consonant place and unstressed syllables. Consequently, voiceless plosives /p, t, k/ were examined separately by changing the reference levels of `Syl` and `Cplace` and re-running the model.[10] Table 5 summarizes the re-running analyses. As VOT is significantly longer in primary stressed syllables than in the other prosodic positions with regards to the three plosives, the relation is excluded from the table. X > Y indicates that VOT given X is significantly longer than that given Y ($p<0.05$). X >. Y indicates that VOT given X is longer than that given Y, but the significance is marginal ($p<0.1$), that is, this does only trend. X = Y indicates that VOT of X and Y is not significantly different ($p\geqq 0.1$).

Table 5: Summary table: significant prosodic effects on VOT

Coronal plosive /t/	Secondary >. *happ*Y Secondary > reduced *happ*Y = reduced
Dorsal plosive /k/	Secondary >. *happ*Y Secondary > reduced *happ*Y > reduced
Labial plosive /p/	Secondary > *happ*Y Secondary > reduced *happ*Y = reduced

In summary, these findings indicate that hypotheses in (3) are basically supported with the exception of one unpredicted relation between the two types of unstressed vowels: the VOT of dorsal plosives differs significantly before reduced vowels than before *happ*Y vowels.

As for non-prosodic variables, there are no main effects of gender, lexical frequency, preceding vowel length, or preceding vowel height. There is, however, a main effect for consonantal type (`Cplace`): /p/ is less aspirated than /k/ ($\beta=-13.84$, $t=-4.76$, $p<0.001$), while /t/ is slightly more aspirated than /k/ ($\beta=5.75$, $t=1.96$, $p<0.1$). This is illustrated in Figure 4. Finally, the result of the subset analysis indicates that plosives are more aspirated before non-high vowels than before high vowels in stressed syllables ($\beta=6.39$, $t=2.46$, $p<0.05$).

5. Discussion

5.1 Lenition and aspiration in NZE

The current paper provides a comprehensive examination of the three voiceless plosives /p, t, k/ in NZE, focusing on word-medial lenition and aspiration. With regards to the former, it was demonstrated that the probability of lenition is affected by prosodic position as in other varieties of English, that is, the degree to which a plosive is lenited is inversely correlated with the degree of stress on the syllable. Although it was previously known that coronal plosives are lenited in a trochaic position in NZE, this study shows that bilabial and dorsal plosives also lenite, a finding consistent with Loakes and McDougall (2010) for Australian English. This finding suggests that /p, k/ also provide interesting test cases to explore leniting phenomena and sociophonetic variation, although /t/ attracts a large amount of attention in previous literature about other varieties of English and NZE. Further, our results indicate that NZE lenition is not categorical, as also found in Liverpool English (Honeybone, 2001) and RP (Buizza & Plug, 2012); that is, lenition occurs to some degree in essentially every prosodic position, with the probability of lenition varying based on prosodic position, as shown in Table 1. It is also remarkable that fricated variants are produced rather than flapped variants as leniting variants generally in NZE. As plosives are often realized as flapped variants in American English (Warner & Tucker, 2010), these findings suggest that NZE is close to British English in terms of leniting phenomena.

Non-prosodic factors were also examined. The significance of consonant place corroborates previous findings from other varieties of English: coronal plosives are most likely to lenite, while labial plosives are least likely. No evidence was found for an effect of vowel height on lenition, supporting Kingston (2008) (cf. Kirchner, 2001). However, there is a significant effect of lexical frequency on the likelihood of lenition. As expected, plosives in higher frequency words were more likely to be reduced, consistent with Bybee (2001). As for preceding vowel length, more leniting variants were observed between stressed short vowels and reduced vowels in our dataset; this finding is in line with Bérces and Honeybone (2012), which argues that cross-linguistically lenition is more likely to occur after short stressed vowels.

This study also documented word-medial aspiration of all three voiceless plosives in NZE, and found that the degree to which a plosive is aspirated is basically correlated with the degree of syllable stress, as expected given previous findings on American English (Lisker & Abramson, 1967; Turk, 1993; Lavoie, 2001; among others). Recall that the difference between secondary stressed syllables and unstressed syllables headed by *happ*Y vowels is nuanced with respect to coronal and dorsal plosives, because their difference is not exactly significant ($p<0.1$). Further exploration is required to test this trend. Also in line with some previous findings on American English (Lisker & Abramson, 1967; Warner & Tucker, 2010; Bouavichith & Davidson, 2013), lexical frequency, preceding vowel length and vowel height do not show any significant effects in the NZE data. However, consonant place and following vowel height do have significant effects that differ in some ways from American English. In particular, while Lisker and Abramson (1967) find that /k/ is the longest plosive in American English, our data show that /t/ is longer than /k/ but the difference is not exactly significant ($p<0.1$). This may be due to the observation that coronal plosives are likely to be affricated in NZE. As for following vowel height, Klatt (1975) finds plosives to be more aspirated before high vowels in American English while the NZE data does not show this to be the case, at least in stressed syllables. This might be related to the proposal by Kirchner (2001), and plosives are phonetically lenited before high vowels and have shorter VOT. We leave further exploration of these findings to future study.

Finally, we would like to point out a limit of the current study. As one of the reviewers pointed out, 'primary stressed syllables' are also 'intonationally pitch-accented syllables' (Gussenhoven, 2004, p. 20) in the current study because of our experimental design. The carrier sentence 'Say _ please' might cause a target word to be pitch-accented as a head of an intonational phrase, the result of which is that a primary stressed syllable is 'stressed and accented' while a secondary stressed syllable is 'stressed but unaccented.' This is why, the difference between primary and secondary stressed syllables might be due to pitch-accents (Turk, 2012) rather than degree of lexical stress in the current study. It would be left for the future study to tease apart the two prosodic properties.

5.2 Effects of unstressed syllables on plosives

As noted in Section 2, reduced vowels and *happ*Y vowels have been impressionistically classified as unstressed vowels in previous literature. The findings in this study from lenition provide empirical evidence for this phonological classification. In particular, there is no significant difference in the number of leniting variants in unstressed syllables headed by reduced vowels and *happ*Y vowels. This finding suggests that the two types of unstressed syllables behave in the same way in this prosody-oriented segmental pattern.

The patterning of syllables with reduced and *happ*Y vowels is more nuanced with respect to degree of aspiration. For bilabial and coronal plosives, there is no significant difference in VOT in syllables with reduced and *happ*Y vowels. On the other hand, dorsal plosives are found to be more aspirated before *happ*Y vowels than before reduced vowels. This difference may be related to the height of the vowels in the two types of syllables; Klatt (1975) found plosives in American English to be more aspirated before high vowels. The result in our data that only dorsal plosive VOT is affected by following vowel height may be linked to the observation that dorsals are produced in the same region of the vocal tract as high vowels (see Chomsky & Halle, 1968). Why the effect of vowel height differs between stressed and unstressed vowels in NZE will be left for future study. Considering following vowel height, it was found that two types of unstressed vowels basically affect the phonetic realization of plosives equally.

These findings contribute to the category of unstressed syllables in phonology, and support the vowel taxonomy in (2) for NZE by showing that these two vowels pattern in the same manner with respect to lenition.

6. Conclusion

This study presents an analysis of word-medial lenition and aspiration affecting voiceless plosives in New Zealand English, and the influence of syllable stress on their realization. In particular, it was found that the lenition and aspiration of the three voiceless plosives /p, t, k/

are conditioned by prosodic position in NZE as in other varieties of English, and are also affected by some non-prosodic variables. By documenting these two phenomena, we also addressed a remaining theoretical issue regarding the status of two vowels (reduced vowels and *happ*Y vowels) that have been classified impressionistically as unstressed in the literature. The current study provides empirical evidence to support this categorization by showing that the two vowels pattern together in lenition and influence the degree of aspiration in some consonant types.

NOTES

[1] This work was funded by LSAP funding from the University of Canterbury. We gratefully acknowledge all the comments at Socio at University of Canterbury and Linguistic Society of New Zealand annual conference 2016. We also wish to thank Andreea Calude for her editing this journal, and two anonymous reviewers for their insightful comments on this study.

[2] Some studies such as Fudge (1984) add a further degree: tertiary stress. In those studies, syllables with full vowels that are more prominent than neighbours have secondary stress, while those with full vowels that are not more prominent than neighbours have tertiary stress.

[3] Chomsky and Halle (1968) and Halle and Keyser (1971) do not explain clearly about the accentuation of word-final syllables. However, it can be understood that word-final non-low tense vowels are not stressed at all, because Tensing Rule [V→[+tense] /##X_##] applies to non-low vowels after the application of Main Stress Rule and Auxiliary Reduction Rule, cf., Chomsky and Halle (1968, p. 111) and Halle and Keyser (1971, p. 58-61).

[4] A similar taxonomy is adopted for Australian English (Cox, 2012, p. 76, 81, 102–106).

[5] As in the generalization in (1), the word-final [oʊ] can also be unstressed in American English despite the full vowel quality. Originally, we planned to examine this vowel as well, but the number of familiar disyllabic words ending with voiceless plosives and [oʊ] is too small in CELEX (Baayen et al., 1995), and thus we did not examine this vowel. It would be left for the future studies.

[6] Notations: X indicates any string, P indicates a plosive, C indicates any consonant, and # indicates a word-final edge.

[7] Following Fiasson (2015, p. 45), aspirated plosives and affricated plosives were collapsed into one category 'stopped variant.' The reason is that the two realizations are difficult to distinguish from visual identification using acoustic spectrograms. As one of the reviewers suggested, stopped variants might be somewhere on a continuum between affricates and plosives in NZE, and the distinction might need to be explored by articulatory analyses rather than acoustic analyses in the future because 'it is not clear whether the release was followed by aspiration or frication noise' (Fiasson 2015, p. 45).

[8] Note that the ratio of coronal fricated variants are not amazingly high, as Fiasson (2015) also reports that about 66% of /t/ in unstressed syllables are mapped onto fricated variants in his data. As was noted in Section 3.3, the current study follows the acoustic classification of plosives employed by Fiasson (2015).

[9] As one of the reviewers pointed out, other sociolinguistic variables (e.g., age and social class) may also affect the likelihood of lenition. We assume that these variables are controlled to some extent, as the participants were recruited at a university. The reason why these sociolinguistic variables were controlled rather than balanced is to keep the experiment simpler (Drager, 2018).

[10] The re-running analyses were performed in the following way. As dorsal plosives and secondary stressed syllables are the reference levels in Table 4, this indicates that dorsal plosives are more aspirated in secondary stressed vs. unstressed syllables headed by reduced vowels ($\beta=-14.58$, $t=-5.36$, $p<0.001$) and marginally so in unstressed syllables headed by *happ*Y vowels ($\beta=-4.93$, $t=-1.68$, $p<0.1$). By changing the reference level of `Syl` to a reduced vowel `unst(@)`, it was found that dorsal plosives have significantly longer VOT in syllables headed by *happ*Y vowels than those with reduced vowels ($\beta=9.64$, $t=3.57$, $p<0.001$). Further, by changing the reference level for `Cplace` to bilabial plosive (lab), bilabial plosives are found to be more aspirated in secondary stressed syllables than in unstressed syllables headed by *happ*Y vowels ($\beta=-13.96$, $t=-4.8$, $p<0.001$). Moreover, a change of the `Syl` reference level to a reduced vowel `unst(@)` revealed no significant difference between the two types of unstressed syllables ($\beta=-0.55$, $t=-0.21$, $p=0.83$). The lack of significance of `Cplace_lab:Syl_unst(@)` in Table 4 suggests that the VOT difference of bilabial plosives when in secondary stressed and unstressed syllables with reduced vowels is identical to that of dorsal plosives ($p<0.001$). As for coronal plosives, changing the reference level of `Cplace` to coronal (`cor`) showed them to be more aspirated in secondary stressed than in unstressed syllables with reduced vowels ($\beta=-7.31$, $t=-2.47$, $p<0.05$); there is no significant difference between the two types of unstressed syllables ($\beta=2.98$, $t=0.99$, $p=0.32$). Similarly, since `Cplace_cor:Syl_unst(i)` was not significant, it suggests that VOT differences for coronal plosives in secondary stressed vs. unstressed syllables with *happ*Y vowels is identical to that of dorsal plosives (i.e. marginally significant $p<0.1$).

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