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Pre-closure laryngeal properties as cues to the fortis–lenis plosive contrast in British varieties of English

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Abstract

The present study contributes to our understanding of the phonetic implementation of the fortis–lenis plosive contrast in British varieties of English via analyses of pre-aspiration and glottalisation. More specifically, we show that pre-aspiration and (pre-) glottalisation can and do function as correlates of the contrast in British English plosives in non-foot-initial position (*la**tt**er* vs *la**dd**er*; *ma**t*** vs *ma**d***). This is in addition to rather than at the expense of the other traditionally discussed potential correlates, with the exception of word-final release duration, where the pre-closure laryngeal phenomena are more robust. We also provide evidence that listeners of a range of accents of British English use pre-aspiration as a cue to the contrast, exhibiting clear categorical perception effects (based on data from 19 listeners). We conclude that the gesture of spread glottis is not necessarily tied to the release phase of the plosive in the relevant varieties of British English but instead can be found prior to the release phase, or indeed both prior to as well as during the release phase itself. Our study thus contributes to the pool of languages known to use pre-closure laryngeal features functioning as correlates of and cues to phonological contrasts (see e.g. Clayton 2009; Kingston 1990; Silverman 1995).

Keywords: Fortis–lenis contrast; laryngeal phonetics and phonology; pre-aspiration; glottalisation; British English.

1. Introduction

It has been claimed that pre-aspiration, a period of voiceless (primarily) glottal friction found in the sequences of sonorants and phonetically voiceless obstruents, is a very rare phenomenon (Silverman 2003 is the typically cited reference for this claim). Post-aspiration, on the other hand, is found in a wide range of the languages of the world. It has been suggested that the reason behind this typological asymmetry is that pre-aspiration is more difficult to perceive (Bladon

1986: 7, in Clayton 2010: 19; but also Kingston 1990 and Silverman 1995), which diminishes its potential to function as a cue to a contrast. One of the tests which this claim could be put to is indeed whether pre-aspiration does function as a cue to any relevant contrast in pre-aspirating languages, and how strong such a cue is in comparison to other cues. Interestingly, current research points out that English is one of the pre-aspirating languages: as we will discuss in section 2.1, pre-aspiration has been recently reported to occur in an increasing number of varieties of the language. In this context, this study asks the following questions:

(1) Can pre-aspiration function as an acoustic correlate of the fortis–lenis contrast in English?
(2) If so, does it also function as a perceptual cue?
(3) If pre-aspiration does function as a correlate of the contrast, does this happen at the expense of other potential correlates, namely release duration and the duration of the preceding vowel?

However, pre-aspiration is not the only pre-closure laryngeal phenomenon that may be of relevance to the fortis–lenis contrast in those English accents that exhibit not only pre-aspiration, but also glottal reinforcement and/or glottal replacement. Glottal reinforcement is a period of glottalisation co-occurring with an oral plosive (e.g. *Matt* [maʔt]) and glottal replacement is also a period of glottalisation, but crucially one which does not co-occur with an (audible) oral plosive release (e.g. *Matt* [maʔ]). As discussed in Section 2.2 in more detail, glottal reinforcement and glottal replacement have also been on the rise in a number of English accents across the globe. In the light of this fact, we then also ask the following question:

(1) Can glottal reinforcement and glottal replacement function as an acoustic correlate of the fortis–lenis contrast in English?

The structure of the paper is as follows. Section 2 presents the reader with an overview of the recent reports of pre-aspiration in a number of English accents (2.1). The same discussion is provided for glottal reinforcement (pre-glottalisation) and glottal replacement (glottalling) in Section 2.2. Other possibly neglected correlates and cues relevant for English accents are introduced (2.3). Section 3 zooms in on the role that pre-aspiration and the two types of glottalisation play in the implementation of the fortis–lenis plosive contrast in

British English, looking into the production of a single speaker of Manchester English. Section 4 provides a perceptual experiment, which targets pre-aspiration as a potential cue of the fortis–lenis plosive contrast in British English spoken in Northern England. The implications and suggestions for further research are provided in Section 5.

2. Phonetic implementation of the fortis–lenis obstruent contrast in English

Phonological contrasts are implemented by a wide range of acoustic correlates, especially regarding the fortis–lenis contrast in obstruents (e.g. Al-Tamimi and Khattab 2011; Kingston et al. 2008; Toscano and McMurray 2010; and the references therein). Apart from the variation associated with the multiplicity of correlates, and cues, languages typically also show variable degrees of socially conditioned variation in the phonetic implementation of phonemes. English accents, for example, show a fairly high degree of variation of the phonetic realisation of fortis obstruents, as discussed further below and in Section 2.3 in particular. This applies primarily to plosives, but the grammar-internal and grammar-external factors influencing the realisation of fricatives have also been noted. Considering the degree of variation reported, it may strike us as somewhat surprising that these socially conditioned variants are not typically included in discussions of potential correlates of the fortis–lenis contrast in the accents in question. Indeed, Hejná and Jespersen (2019) show that lesser-investigated socially conditioned variants in obstruents can be variably exploited as correlates of the fortis–lenis contrast by English speakers.

2.1. Pre-aspiration

As mentioned in Section 1, pre-aspiration has been recently reported in an increasing number of English accents, including in the environment of post-vocalic plosives and/or fricatives in Australian English (Tait and Tabain 2016), Hebrides English (Clayton 2017), Liverpool English (Watson 2007: 171, 183, 201), Manchester English (Hejná and Scanlon 2015), Middlesbrough English (Jones and Llamas 2003), North American English (Clayards and Knowles 2015), Scottish Standard English (e.g. Gordeeva and Scobbie 2010, 2013), Standard Southern British English (Kettig 2015), Tyneside English (e.g. Do-

cherty and Foulkes 1999), and Welsh English (Hejná 2015, 2016b; Morris 2010). Importantly, pre-aspiration is reported to occur only in fortis obstruents in these varieties of English.

The first mention of pre-aspiration as relevant for the implementation of the fortis–lenis contrast in English is found in Gordeeva (2007: 435), who finds that there is increased voiceless glottal friction associated with word-final /s/ in comparison to /z/ in Scottish Standard English (SSE) and Southern Standard British English (SSBE), in contrast to Russian. Corroborating evidence is found in a later study (Gordeeva and Scobbie 2010), which shows that the /s/–/z/ contrast manifests itself through pre-aspiration in /s/ word- and phrase-finally. Yet further evidence showing the same effect is provided by Gordeeva and Scobbie (2013), who focus on the foot-final fricative contrast (embedded in a sentence and thus found in an intervocalic environment) between /s/ and /z/ (/θ/ and /ʃ/ are also included in the analyses, but the corresponding lenis fricatives are not). Hejná (2016a) and Hejná (2015, chapter 6) note that pre-aspiration functions as a very robust correlate of the fortis–lenis plosive contrast in Aberystwyth English (mid Wales), thus providing us with the first evidence of its relevance to the contrast in the plosive context as well, albeit for a variety of English spoken in a different region. In Aberystwyth English, pre-aspiration functions as a correlate of the contrast foot-finally (e.g. *co**t*** vs *co***d***) as well as medially (e.g. *la**t**ter/la**dd**er*), irrespective of phrase position. Finally, Clayton's (2017) analysis of Hebrides English pre-aspiration focuses only on phonologically voiceless plosives, but conveniently tokens with phonologically voiced plosives were included as distractors in the study. Whilst Clayton does not comment on the absence of pre-aspiration in the lenis series in the study, pre-aspiration is indeed limited solely to the fortis series in Hebrides English (Clayton, personal communication, 2018), similarly to Aberystwyth English.

Apart from being limited to a handful of regions, the studies discussed above also restrict themselves to production; Clayton (2009) provides the only perceptual investigation (see below). Although pre-aspiration can function as a fortis–lenis correlate in some accents of English, does it in fact also function as a perceptual cue to the contrast?

As mentioned, from a typological perspective, pre-aspiration is considered to be a rare phenomenon (e.g. Maddieson 1984; Silverman 2003), which leads to a typological asymmetry between pre-aspiration and post-aspiration, the latter of which is frequently attested in the world's languages. More precisely, Clayton (2009) reports that whilst 25.5% of the UPSID languages feature post-aspirated plosives, fewer than 1% feature pre-aspiration. Clayton is the first to suggest

(contra to Kingston 1990; Silverman 1995) that the rarity of pre-aspiration is not due to any perceptual disadvantage over post-aspiration, but because pre-aspiration innovates less frequently than post-aspiration, i.e. pre-aspiration – for whatever reason – emerges in an individual's speech less frequently than other phenomena such as the frequent emergence of palatalized consonants in the context of high front vowels (Campbell 2004: 41–42; Ohala 1983: 204–205). This proposal is consistent with the suggestion that a language most likely needs to have coda obstruents that are not only phonetically voiceless but also post-aspirated in order to develop pre-aspiration to begin with (see Hejná 2015: Section 3.11). Clayton backs up his proposal with perceptual experiments (2AFC, "same/different"), which show that Polish-speaking subjects performed worse with a foot-initial post-aspiration distinction ([TV_1d] vs [T^hV_1d]) than one based on medial pre-aspiration ([dV_1Ta] vs [$dV_1{}^hTa$]). However, Clayton does not make a direct comparison between the two potential cues within a single prosodic environment, which unfortunately makes his study somewhat problematic in terms of the perceptually motivated asymmetry hypothesis. More work is clearly needed to shed light on whether perceptual accounts of the markedness of pre-aspiration are on the right track, and how many of the few pre-aspirating languages actually use pre-aspiration as a *cue* to the fortis–lenis contrast, rather than solely a production correlate.

2.2. Pre-glottalisation and glottalisation

The alveolar plosive /t/ has been widely reported to undergo glottal reinforcement (pre-glottalisation) and/or glottal replacement (glottalling), for example in American English (Eddington and Taylor 2009; Eddington and Channer 2010), Australian English (Su 2007; Tait and Tabain 2016), Cardiff English (Mees and Collins 1999), Dublin English (Wells 1982: 430), Newfoundland and Labrador English (Clarke 2010: 54–55), and RP (e.g. Fabricius 2002). Fortis plosives associated with other places of articulation (/p/ and /k/) have also been reported to undergo either of the two or both phenomena in a number of accents, although less frequently than /t/ (American English – Seyfarth and Garellek 2015; Australian English – Fox and Palethorpe 2007, Su 2007; Belfast English – Wells 1982: 445; Edinburgh English – Chirrey 1999: 226; English-origin speech in Newfoundland and Labrador – Clarke 2010: 19 and 54–55; Glasgow English – Stuart-Smith 1999: 208–209; Manchester English – Hejná and Scanlon 2015; Newcastle English – Watt and Milroy 1999: 30; Docherty and Foulkes 1999;

Sandwell English – Mathisen 1999: 110; Sheffield English – Stoddart et al. 1999: 75–76; South East London English – Tollfree 1999: 170). Generally, however, the extension of glottalisation to contexts other than /t/ is to be found in British English (Docherty and Foulkes 1999: 1037 for further references).[1]

Interestingly, pre-aspiration and pre-glottalisation can be involved in allophonic relationships, which complicates their potential contribution to contrast implementation and perception. Hejná and Scanlon (2015) note that pre-aspiration and glottalisation are allophonic in Manchester English, with pre-aspiration found in 92% of the plosive tokens foot/word-medially (but not foot/word-finally), and glottalisation in 98% of the plosive tokens foot/word-finally (but infrequently foot/word-medially); pre-aspiration was also found to be obligatory in fortis fricatives, analysed for the final position only. Whilst this fairly strict complementarity suggests that pre-aspiration and pre-glottalisation are phonologically conditioned, it is unclear to what extent the two laryngeal phenomena contribute to the implementation and the perception of the fortis–lenis obstruent contrast in Manchester English (or indeed most other varieties of English).

Gordeeva and Scobbie (2013) are the first to inform us that glottalisation can be associated with fortis as opposed to lenis plosives in their study of SSE, where they focus on the word-final position (again words embedded in a carrier sentence). Their study is the first to establish the role of glottalisation in the implementation of the fortis–lenis contrast in an English accent. More recently, although Hejná (2016a) has shown that pre-aspiration functions as a correlate of the fortis–lenis plosive contrast in Aberystwyth English, interestingly one of the speakers only used pre-aspiration as a correlate of the contrast foot-medially, whereas she used pre-glottalisation foot-finally, mirroring the findings available for Manchester English. Following Gordeeva and Scobbie (2013), Hejná (2016a) is the second study to show that pre-glottalisation and pre-aspiration can function as correlates of the fortis–lenis plosive contrast in British English. Importantly, Hejná's (2016a) speakers are all L1 Welsh speakers and it is therefore difficult to assess the extent to which this represents the implementation of the contrast in British English (as opposed to L1 influence regarding pre-aspiration).

Based on Kingston (1990), we would expect glottalisation to be less likely to function as a correlate of or a cue to contrasts in the world's languages, although Garellek (2013: 2.1) reports that the UCLA Phonological Segment Inven-

[1] This list is intended to be representative, not exhaustive.

tory Database lists glottal stops in 47.9% of the world's languages. Glottal stops are clearly a fairly frequent phenomenon; however, what is less clear is how frequent they are when articulated with oral plosive releases, as in glottal reinforcement in English varieties.

The traditional account of the phonetic implementation of the fortis–lenis plosive contrast in English is that it is post-aspiration, or long VOT (see Hejná 2016a: 3150, referring to Gallagher 2011), that is the torchbearer of the phonological distinction between /p, t, k/ and /b, d, g/. A richer traditional account of the phonetic implementation of the contrast takes into consideration a wider number of correlates, which include the duration of the preceding vowel, F1, F2, and F3 transitions, spectral characteristics of the burst, F0 (see e.g. the references presented in Vaux and Samuels 2005: 414), and – depending on the individual and the dialect – voicing (e.g. Scobbie 2005). Fewer studies have shown that the duration of the *following* vowel can also function as a correlate of the contrast in American English (Allen and Miller 1999: 2031) and Aberystwyth English (Hejná 2016a). In Australian English, when phrase-final stops are not released, it is typically the duration of the preceding vowel that distinguishes the fortis–lenis plosive contrast (Fox and Palethorpe 2007: 343).

2.3. Obstruent variation and other possible correlates of the English voicing contrast

Pre-aspiration, and pre-glottalisation and glottalling are not however the only aspects that characterise the variation found in the obstruents of English accents and that could be important in the implementation of the fortis–lenis obstruent contrast in these accents. Other phenomena that may be relevant for the implementation of the fortis–lenis plosive contrast are the flapping of alveolar plosives (reported for /t/ and /d/ in North American and Australian accents; Bermúdez-Otero 2004; Braver 2011; Fox and Palethorpe 2007: 342–343; Su 2007; Tait and Tabain 2016; Turk 1992; Zue and Laferriere 1979; reported for /t/ in New Zealand English – e.g. Silby 2008), the T-to-R rule (some varieties of English in the British Isles – Buchstaller et al. 2013: 89, 92, 98–99; Clark and Asprey 2013: 67–68; Wells 1982: 370; Newfoundland English – Clarke 2010: 53; New Zealand English – Hay et al. 2008: 20, 38), affrication (Australian English – Su 2007; Tait and Tabain 2016; British English - Buizza and Plug 2012; Hejná 2015: 344, 2016a; Hejná and Jespersen 2019; Mortensen 2017; Sangster 2001; Wells 1982: 388), post-aspirated affrication (Hejná 2015: 344; 2016a;

Mortensen 2017; Su 2007: 27 and 31), slit-t/d and spirantisation (varieties in the British Isles – Beal 2010: 83–84; Hejná and Jespersen 2019; Hickey 1996, 2004; Jones and Llamas 2003; Watson 2007; Wells 1982: 371–372 and 429–430; in the Irish-settled Avalon Peninsula in Newfoundland – Clarke 2010: 54; Australian English – Tait and Tabain 2016; Su 2007), lack of aspiration in fortis plosives (in some varieties of British English – Wells 1982: 370, 408–409), consonantal reductions and dentalisation phenomena (e.g. Australian English – Su 2007: 9), and closure duration variation (see e.g. the comments on Welsh English lengthened consonants in Wells 1982: 388).

Although fricatives have not enjoyed as much reported socially conditioned variation as plosives, in some accents of British English fortis fricatives have been reported to show pre-aspiration (as noted in section 2.1 above), post-aspiration (Hejná 2015: 270; Wells 1982: 388), dentalisation processes (e.g. Bell and Gibson 2008; Fought 2003: 67; Newlin-Lukowicz 2013; Wells 1982: 329), even glottal replacement (Wells 1982: 327), potentially the fronting of the dental fricatives (see e.g. Stuart-Smith et al. 2013), and one of the reviewers also draws our attention to the /z/ to [d] rule found e.g. in Southern States American English (Reynolds 1994).

These obstruent variants would contribute to the contrast implementation only if one of the members was more likely to undergo the process than the other (as is the case for example in the /t/–/d/ contrast in Czech, where some speakers produce a pre-alveolar /t/ but an alveolar /d/; Skarnitzl 2011: 146–147). The question thus remains whether the variation reported to occur in English obstruents is of relevance to the fortis–lenis obstruent contrast. In line with Vaux and Samuels (2005: 410), we would expect that a contrast between a phonetically voiced lenis plosive (D) and a phonetically voiceless post-aspirated fortis plosive (T^h), for example, is easier to perceive than that between D and T, and T and T^h; in other words, increased variability feeds into dispersion/enhancement. This makes it possible for any variation to be meaningful for the contrast, at least in theory. Importantly, however, we also agree with Scobbie (2005: 1) that "subtle differences in pronunciation targets between speakers can easily be found [...], but it is when they are *systematic* that they take on linguistic significance". The nature of the systematicity of the phenomena reviewed in this section is subject to further research regarding the fortis–lenis contrast. This paper contributes to this issue with analyses of pre-aspiration and pre-glottalisation in what follows.

3. Manchester English: A production case study

In 2016, the second author recorded one of the five speakers analysed for laryngeal properties of fortis obstruents by Hejná and Scanlon (2015), collecting not only tokens with fortis plosives but crucially also lenis plosives. This was done with the perceptual study presented here in mind. Both fortis and lenis plosive tokens were therefore obtained in order to create stimuli for the perceptual experiment targeting pre-aspiration, and pre-glottalisation and glottalling as potential cues to the fortis–lenis plosive contrast (Section 4 below). This provided us with the minimal pairs found in the Appendix. Wordlist evidence was used by Gordeeva (2007), Gordeeva and Scobbie (2010, 2013), and Hejná (2016a), which is why the same speech task was opted for here. Since there is however no existing data on the phonetic implementation of the fortis–lenis contrast in Manchester English, the data collected were used to establish parameters for synthesising stimuli to be used in the perceptual experiment and were also analysed acoustically to shed light on what role pre-aspiration, and pre-glottalisation and glottalling may play as potential correlates of the fortis–lenis plosive contrast as well. Other potentially relevant phenomena were also analysed, namely those of release duration, the duration of the preceding vowel, presence of voicing and its extent (partial or complete), and spirantisation and its extent.

The total number of tokens collected from the participant equals 110. 55 tokens represent a ˈCVC structure and 55 tokens represent a ˈCVCV structure. The fortis types within the ˈCVC structure were *lap*, *Matt*, and *lack*; the lenis types were *lab*, *mad*, and *lag*. The fortis types within the ˈCVCV structure were *dapper*, *latter*, and *stacker*; the lenis types were *dabber*, *ladder*, and *stagger*. Each ˈCVC type was read three times in the carrier sentence *Please say ___ again*. Each ˈCVCV type was read three times in the carrier sentence *Please say ___ constantly*. In addition, three rounds of contrastive sentences were obtained; e.g. *I said lag, not lack.*, *I said lack, not lag.*, *I said stagger, not stacker.*, and *I said stacker, not stagger*.

The speaker was recorded in the recording booth at the University of Manchester. She was wearing a head-mounted AKG C520 microphone, which was used in conjunction with H5 Zoom recorder. The sampling rate was 44.1 kHz. As mentioned, the speaker chosen for the analysis in the current study is one of the five speakers analysed in Hejná and Scanlon (2015), and the only one who could be rerecorded for the fortis–lenis analysis extension.

The first author segmented the tokens manually in Praat (Boersma and Weenink 2016) and identified all cases of pre-glottalisation, glottalling, and pre-aspiration, as well as those of the other targeted phenomena. The identification criteria and the behaviour of each phenomenon is reported below, starting with pre-aspiration and breathiness, and subsequently proceeding to glottalisation (including pre-glottalisation and glottalling), release and vowel duration, presence of voicing, and presence of spirantisation.

3.1. Pre-aspiration and local breathiness

In line with Hejná (2015, 2016a), Hejná and Scanlon (2015), and Morris and Hejná (2019), pre-aspiration was defined narrowly as a period of (primarily) glottal friction occurring in sequences of sonorants and phonetically voiceless obstruents, and was distinguished from local breathiness, which differs from pre-aspiration by the presence of voicing (see Figure 1). For the reasons behind this decision, see e.g. Hejná (2015), who shows that the two may not be subject to the same language-internal and language-external constraints.

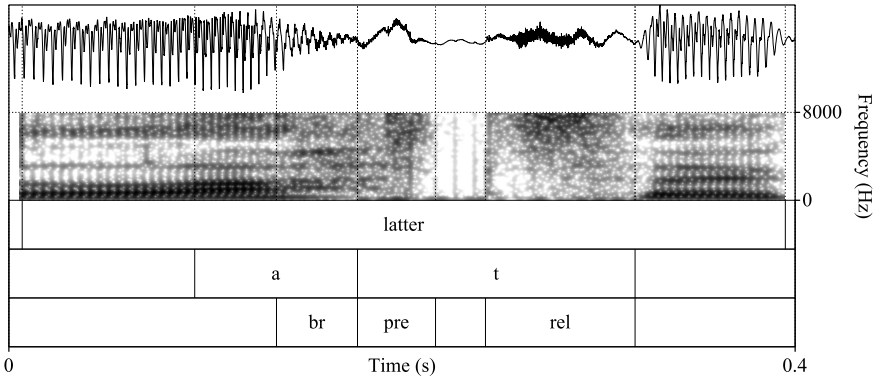

Figure 1. Example of pre-aspiration ("pre") and local breathiness ("br"); "rel" = release.

The results illustrate fairly clearly that the Manchester English speaker utilises both pre-aspiration and local breathiness as acoustic correlates of the fortis–lenis plosive contrast in the speech task at hand, and that she does so in exactly the

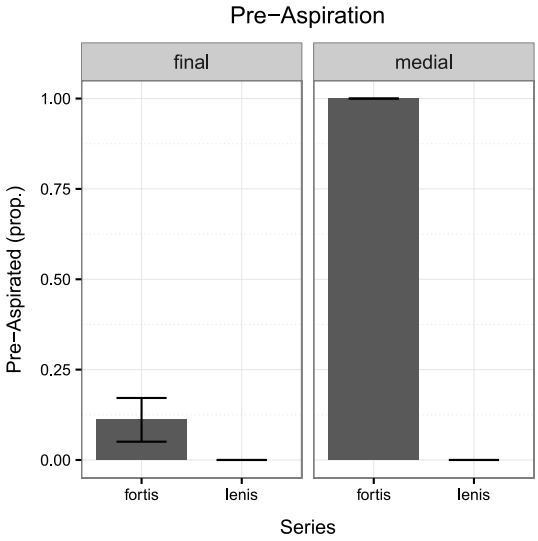

Figure 2. Presence of pre-aspiration by series across word-final and word-medial positions. Error bards represent 95% Confidence Intervals.

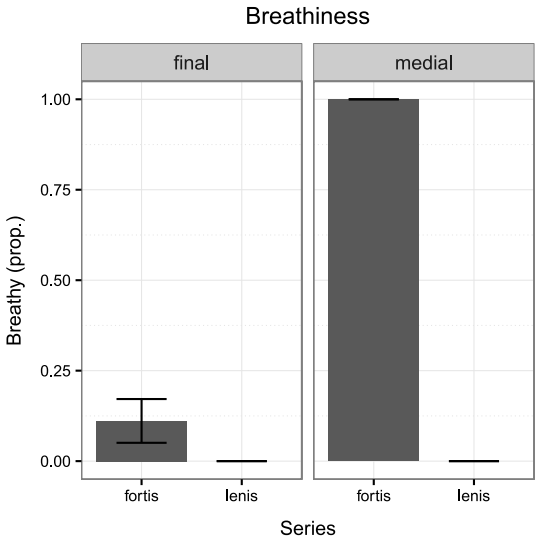

Figure 3. Presence of local breathiness by series across word-final and word-medial positions. Error bards represent 95% Confidence Intervals.

same way for these two phenomena. As Figures 2 and 3 show, both phenomena are limited to the fortis series and are further restricted primarily to the medial position, where they apply strictly obligatorily in 100% of the cases (n = 55). Four instances of pre-aspiration and local breathiness are found in the fortis tokens in the final position as well. These results are in line with those of Hejná and Scanlon (2015), who argue that pre-aspiration and local breathiness fulfill the same linguistic function in the variety.

3.2. Pre-glottalisation and glottalling

In order to identify glottalisation, we employed the same criteria as those used in Hejná (2015, 2016a) and Hejná and Scanlon (2015). Two types of acoustic profiles were considered as positive occurrences of glottalisation: irregular glottal pulses and a sudden drop in F0. (See Figure 4 for an example.) Glottalling, or glottal replacement, was identified based on these two criteria as well; however, an additional criterion was a lack of visible oral release, which is how pre-glottalisation and glottalling were distinguished.

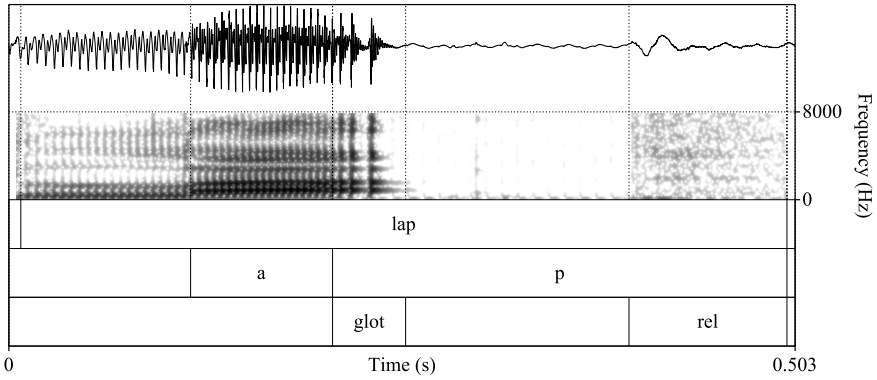

Figure 4. Identification of glottalisation ("glot"); "rel" = release.

The participant produced four instances of glottalling, all of which occurred in the word *Matt*. On the one hand, this makes glottalling restricted to the fortis se-

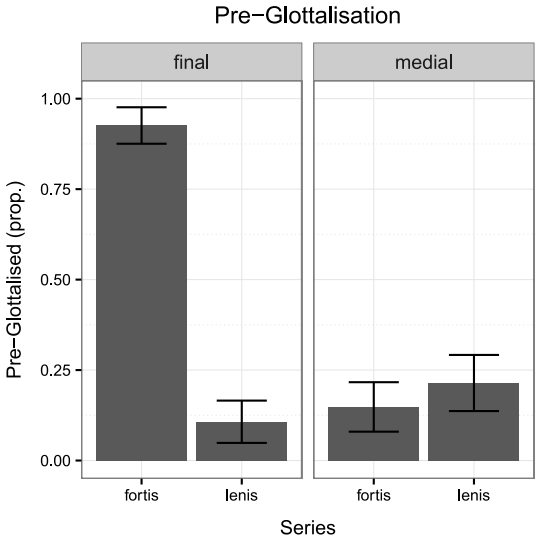

Figure 5. Glottalisation across word-final (left)
and word-medial (right) positions. Error bards represent 95% Confidence Intervals.

ries; on the other, the frequency is too low for it to be meaningful for the contrast implementation, at least in a formal speaking setup. Regarding pre-glottalisation, or glottal reinforcement, the results show that the Manchester English speaker utilizes pre-glottalisation as an acoustic correlate of the fortis–lenis plosive contrast in final position, as shown in Figure 5. Nevertheless, as Figure 5 also suggests, the situation is less clear-cut for glottalisation than it is for pre-aspiration and local breathiness.

Pre-glottalisation occurs in fortis plosives in the final position in 96% of the cases (n = 24/25). In the remaining 4% of the cases (n = 1), pre-aspiration and local breathiness are found instead. This means that pre-aspiration and pre-glottalisation(/glottalling) are strictly complementary in the fortis series in the final position. However, instances of glottalisation are also found in the fortis series medially in 14% of the cases (n = 4/27), where they co-occur with local breathiness and pre-aspiration. Furthermore, glottalisation occurs in the lenis series as well, where it is found in 15% of the cases .both finally (n = 4/29) and medially (n = 4/28).

Any analyses of (sub-)segmental glottalisation beg the question whether we are in fact dealing with glottalisation which is of a primarily (sub-)segmental na-

ture: it is tempting to relegate these instances of glottalisation to utterance-final effects instead (see e.g. Huffman 2005: 338, 351, 356; Kreiman 1982; Redi & Shattuck-Hufnagel 2001). We would like to argue here that this may indeed be the case, but crucially not for the word-final fortis plosives.

The cases of glottalisation as found in the sequences of vowels and plosives in the final fortis context show a very consistent timing of glottal pulse aperiodicity with respect to the closure of the plosive, occurring immediately prior to the closure and at the end of the vowel (if we decide to consider glottalisation as part of the vowel). In other words, the glottalisations in this context follow the modal part of the vowel in the vast majority of cases. More specifically, in final fortis plosive tokens (e.g. *Matt*), glottalisation is found between the modal part of the vowel and the closure in 23 out of 25 cases (92%) and the *whole* vowel is realised with glottalisation in the remaining two cases (8%), where it could fulfill a number of linguistic functions. Importantly, the timing of the glottalisations found in the fortis medial tokens and in the lenis tokens is rather different. The glottalisation found in these environments is distributed equally across various possible positions with respect to the vocalic segment; it occurs vowel-initially, vowel-medially, vowel-finally, and also throughout the vowel. None of these environments is preferred. We therefore interpret the consistency in the timing of the glottalisation between the modal part of the vowel and the plosive closure in the final fortis plosive tokens as an indication that we are in fact dealing with a (sub-)segmental type of glottalisation rather than an utterance-position or turn-position related glottal phenomenon, in line with Hejná and Scanlon (2015).

3.3. Release duration and the duration of the preceding vowel

As mentioned, the expected primary correlates of the contrast in English are the release duration and the duration of the preceding vowel. The release duration was measured from the beginning of the burst until the onset of periodicity. Since the tokens occurred in a carrier sentence, even the final tokens were followed by a voiced segment. The durational measurements of the vocalic interval importantly excluded voiceless pre-aspiration and vowel-final glottalisation, i.e. vowel duration in this study refers to a vocalic interval that shows periodicity. It could of course be the case that pre-aspiration and glottal reinforcement are part of the vowel, rather than that of the consonant. However, unless it is known whether the laryngeal phenomenon is in fact affiliated with the periodic vocalic component, it is not safe to assume that it is: it may well be affiliated with the

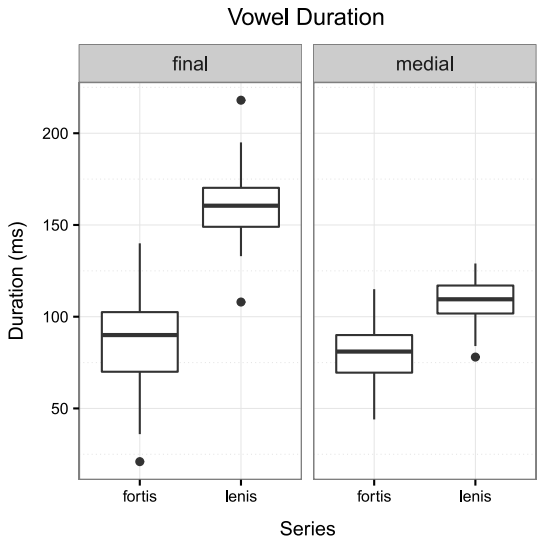

Figure 6. Duration (ms) of the preceding vowel by series for the word-final and word-medial positions.

consonant, both the vowel and the consonant, or neither. For a discussion of this, see Stevens and Reubold (2014) and Hejná (2015: 31–36). This is why we focus only on the periodic component of the signal here.

As visible in Figure 6, the duration of the periodic component of the preceding vowel is longer in the lenis context than in the fortis context, irrespective of word-position (lenis mean finally = 161ms, fortis mean finally = 86ms; lenis mean medially = 108ms, fortis mean medially = 90ms). Regarding release duration, as Figure 7 reveals, we find the expected difference medially, where the lenis plosives have a noticeably shorter release duration (mean = 15ms) than the fortis plosives (mean = 55ms). Word-finally, the duration of the release does not indicate a reliable acoustic correlate, with the lenis tokens exhibiting somewhat surprisingly high values (lenis mean = 67ms; fortis mean = 62ms). See Figure 8, which shows an example with a long lenis release.

Although ejectivisation of the release was not one of the targeted aspects, we also report here that four foot-final fortis plosives were ejectivised (4% of the whole dataset). All of these cases are represented by the velar place of articulation (*lack* in three cases, *lag* in one case).

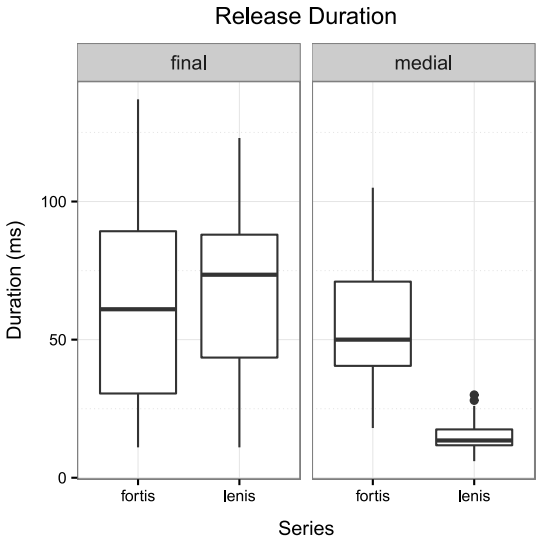

Figure 7. Release duration (ms) by series
for the word-final and word-medial positions.

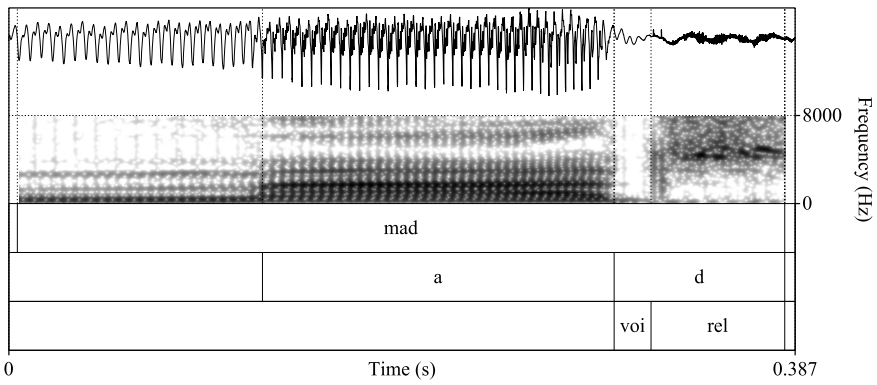

Figure 8: Affrication of /d/; “voi” = voicing, “rel” = release.

3.4. Voicing during closure

The presence of voicing was identified on the basis of the presence of periodicity during the closure interval (Figure 8). We further distinguished two broader

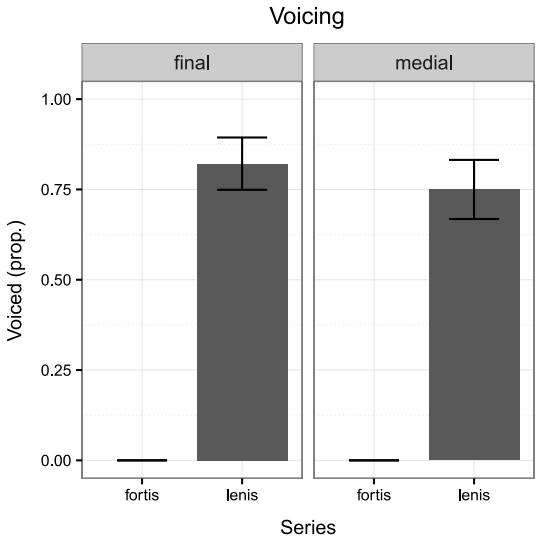

Figure 9. Voicing rate by series.

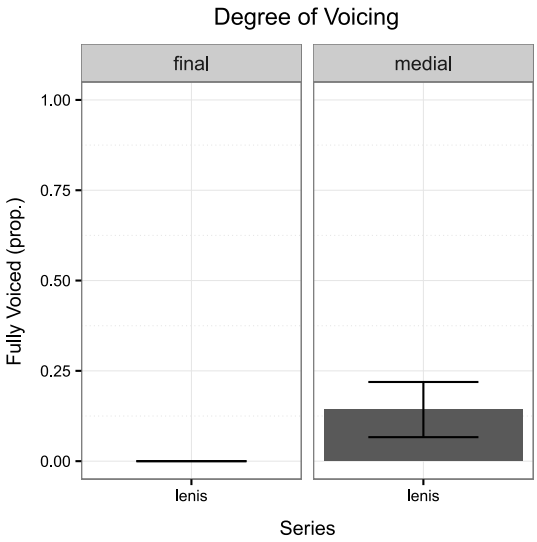

Figure 10. Degree of voicing by series.

types of voicing: firstly, we noted instances where the whole plosive was voiced (= "full" voicing); secondly, we noted cases where the voicing was partial as it did not last throughout the entire plosive segment (= "partial" voicing).

Voicing is found in 44 instances of the lenis tokens (79% of the lenis data) and never occurs in the fortis context. In the lenis series, voicing occurs in 23 cases word-finally (82%) and in 21 cases medially (75%). Voicing is partial in 41 cases (93%) and complete in 3 cases (7%). These results are shown in Figures 9 and 10.

3.5. Spirantisation

Spirantisation was identified by the absence of a burst associated with plosives. Two types of spirantisation were distinguished: full spirantisation, in which case there was no closure, and partial spirantisation or semi-spirantisation (see Stevens and Hajek 2005), in which case the closure of the plosive was clearly visible, but the burst was not. Semi-spirantisation is illustrated in Figure 11.

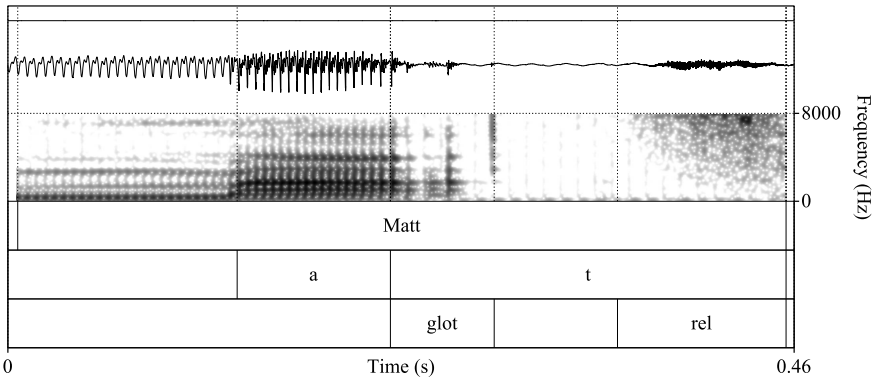

Figure 11. Example of semi-spirantisation; "glot" = glottalisation, "clo" = closure, "rel" = release.

As Figure 12 shows, spirantisation occurs in 27 cases within the whole dataset (25%) and is not limited to one type of the two series. We find it in 11 cases in the lenis context (20%) and 16 cases in the fortis context (30%), after we exclude the four glottalled tokens from the calculations. The majority of the spi-

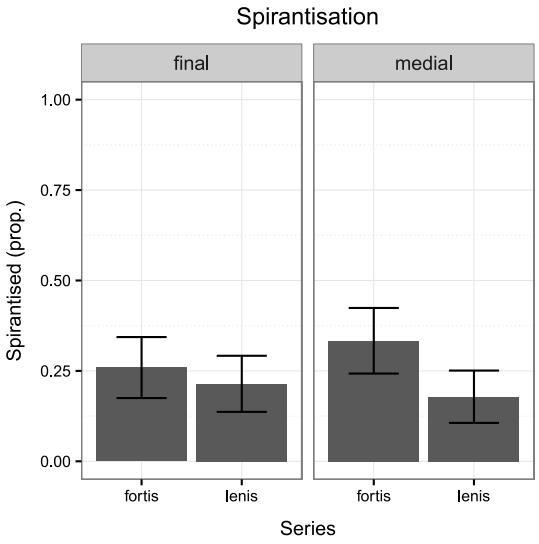

Figure 12. Spirantisation rate by series.

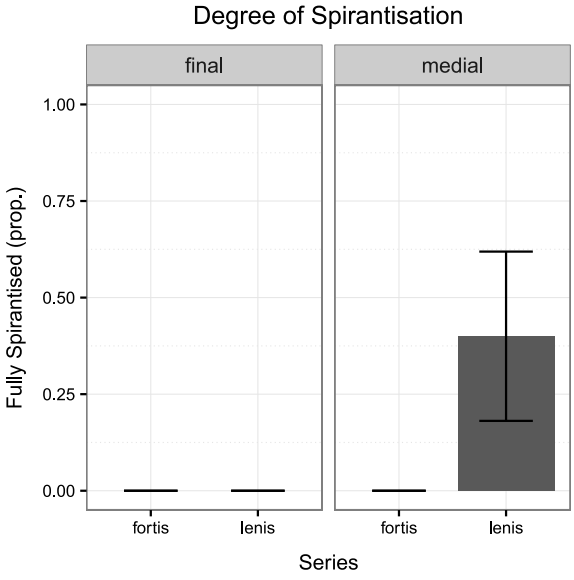

Figure 13. Type of spirantisation by series

rantised cases (25 cases, 93%) are cases of semi-spirantisation and only 2 cases (7%) are instances of full spirantisation (Figure 13). This evidence does not clearly suggest that spirantisation would contribute to the implementation of the contrast.

While this case study presents data from only a single speaker, it has provided a fairly detailed analysis of the realisation of the fortis–lenis contrast at the level of the individual grammar. To summarise, the speaker uses the expected correlates of the fortis–lenis plosive contrast, namely the duration of the preceding vowel, which is longer in the context of lenis plosives; the duration of the release, which is longer in the context of fortis plosives, although this is the case word-medially and not finally; and the presence of voicing, which is associated with the lenis series. The other traditionally acknowledged correlates of the contrast were not analysed here (formant transitions and F0). Our analysis also revealed that other aspects are employed as correlates of the contrast. Pre-aspiration and local breathiness are associated with medial fortis plosives with maximal application and marginally occur in the fortis context also finally. Glottalisation which is consistently timed to the position immediately preceding the closure is found finally in the fortis plosives; in other contexts, the timing of the glottalisation is not consistent and may be due to prosodic creak (see e.g. Keating et al. 2015). Glottal replacement was found in 4 cases, similarly to ejectivisation, and both phenomena were limited to the final fortis context. Glottal replacement always affected /t/ and ejectivisation /k/. Whilst previously unreported spirantisation was reported here, it is not clearly associated with one series only.

4. Perception of pre-aspiration

The results of the case study presented in Section 3 above, when taken together with previous findings from Hejná (2015), Hejná and Scanlon (2015), and Hejná (2016a), establish that pre-aspiration and pre-glottalisation are both utilised by speakers as acoustic correlates of the fortis/lenis contrast in at least some dialects of British English. However, this behaviour on the part of speakers does not necessarily indicate that this acoustic information is available to or utilised by listeners.

This section presents the results of a perceptual study designed to investigate whether pre-aspiration is a cue that listeners are able to use in distinguishing fortis and lenis plosives. This study made use of both identification and discrimination tasks; following Pisoni (1973), we expect to find a relationship between the two tasks if pre-aspiration is indeed perceived categorically. We do indeed find

that identification scores predict discrimination, and we conclude that pre-aspiration can indeed serve as a perceptual cue to the fortis–lenis contrast.

4.1. Methodology

The subjects in this study consisted of 19 native speakers of British English (primarily from the North of England), who reported no speech or hearing disorders and participated for course credit.[2] Stimuli consisted of 8-step Klatt-synthesised pre-aspiration continua (20ms increments, beginning from zero) for labial, coronal, and dorsal plosives. The range of the continuum (from 0ms pre-aspiration to 160ms) was chosen to approximate the range of values seen in sample production data; the increments were chosen to balance detail and overall discriminability. Only the vowel [a] was used, and the stimuli included plosives in both final (aC) and medial (aCa) position; all other cues to the fortis/lenis contrast were held constant. Post-aspiration/VOT was 35ms, and no voicing was present in the closure; F0 at the onset of the following vowel was 100 Hz (declining to 75 Hz at vowel offset); duration of the preceding vowel (excluding the interval of pre-aspiration) was 250ms, and the duration of the following vowel in VCV items was 225ms.

Speeded 2AFC identification and discrimination tasks were presented to subjects in separate blocks, using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA); within each block, subjects were periodically offered brief breaks, with a longer break between blocks. Responses were collected using the Serial Response Box from Psychology Software Tools. The experiment took place in a sound-attenuated booth, and stimuli were presented auditorily (at a comfortable volume) via supra-aural headphones.

In the identification task, during each trial subjects were presented with a single stimulus and asked to make a pairwise judgement (e.g. p vs. b) by selecting right or left buttons corresponding with orthographic representations on the computer screen; with eight continuum steps, three places of articulation, and two foot positions, there were a total of 48 unique stimuli. Subjects heard each item four times (twice with the fortis member of the pair on the left, and twice with the lenis member of the pair on the left).

In the discrimination task, during each trial subjects were presented with sequential pairs of stimuli (with an ISI of 750ms) and asked to make a same/dif-

[2] Subjects were excluded if they gave more than 15% null responses across the duration of the experiment. No subjects were excluded for this reason.

ferent judgement. For all places of articulation and positions, subjects heard each step in the continuum paired with itself and with the immediately adjacent steps (in both ascending and descending order), for a total of 132 unique pairs. Subjects heard each pair twice.

For both tasks, items were presented in pseudo-random order. The time limit for each trial was 3000ms for the identification task, and 2000ms for the discrimination task.

4.2. Results and discussion

The results of the identification and discrimination tasks can be seen in Figure 14 and Figure 15. Data have been pooled across places of articulation and foot position – while both showed small but detectable effects, neither interacted with the main effects under consideration, and they can safely be aggregated.

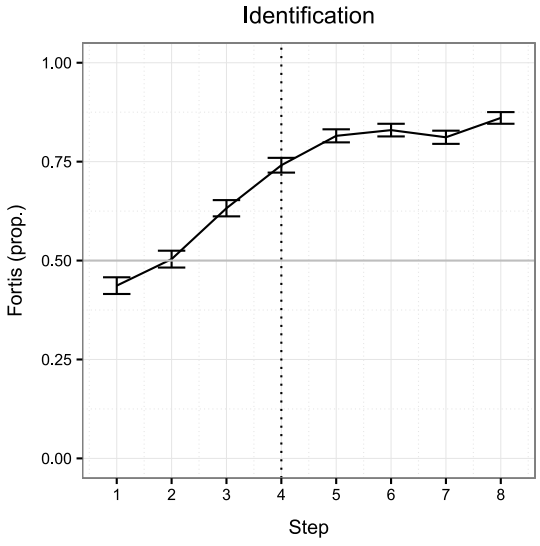

Figure 14. Proportion fortis responses in the identification task. Error bars represent 95% binomial confidence intervals, and vertical dotted line corresponds to the sensitivity threshold in Figure 14. Solid grey line at chance (50%) for reference.

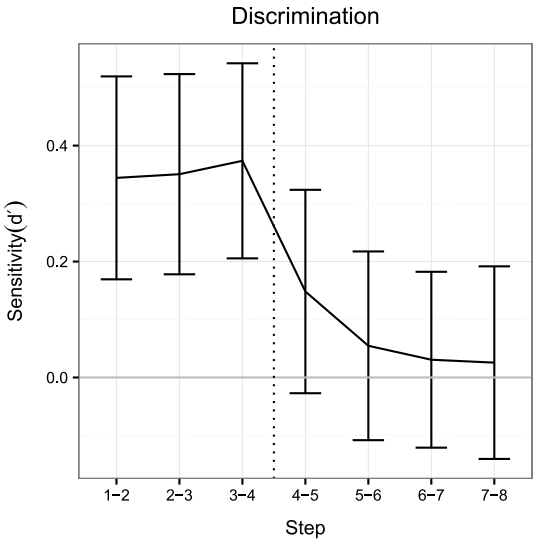

Figure 15. Sensitivity (d′) in the identification task. Error bars represent 95% confidence intervals, calculated using the Gourevitch and Galanter (1967) method presented in Macmillan and Creelman (2005: 325); vertical dotted line indicates chance threshold. Solid grey line at zero for reference.

Beginning with identification, we can see from Figure 14 that subjects were at or near chance for the first two steps of the continuum (0ms and 20ms of pre-aspiration), suggesting that the parameters chosen for the stimuli produced a plosive that was ambiguous along the fortis/lenis dimension. By step 5 (80ms of pre-aspiration) subjects reached a plateau, identifying these items as fortis on approximately 80% of trials. In other words, holding all other cues constant but including an interval of pre-aspiration was sufficient to reliably produce fortis perception in an otherwise ambiguous stimulus.

Turning now to discrimination in Figure 15, we can see first of all that subjects' performance was quite poor across the board – this is consistent with what was discovered through informal debriefing of subjects, nearly all of whom commented on the difficulty of the task. However, subjects did perform above chance when discriminating steps 1 and 2 (0ms vs 20ms pre-aspiration), 2 and 3 (20ms vs. 40ms pre-aspiration) and 3 and 4 (40ms vs. 60ms pre-aspiration), but with longer pre-aspiration intervals performance was not distinguishable from chance.

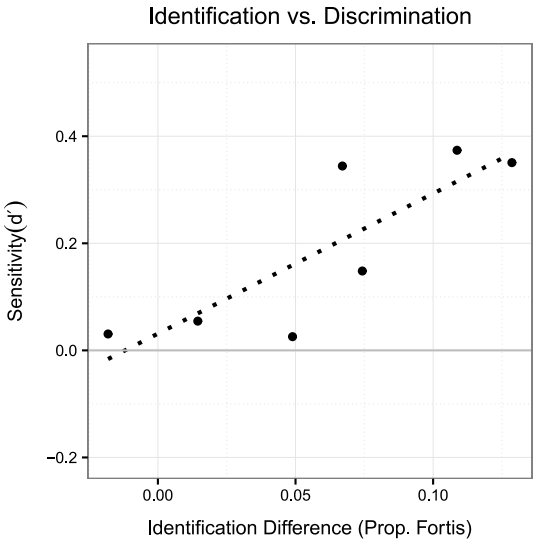

Figure 16. Sensitivity (d′) as a function of the difference in fortis identification between steps, with (dotted) linear regression line.
Solid grey line at zero for reference.

Comparing Figure 14 and Figure 15, we can see that the point at which subjects' performance on the discrimination task becomes indistinguishable from chance corresponds approximately to the beginning of the fortis plateau in the identification task. Figure 16 shows the relationship between the difference in identification between adjacent steps and subjects' sensitivity in distinguishing those steps. There is a statistically significant large correlation ($p < 0.05$, $r = 0.83$), suggesting that there is indeed a relationship between identification and discrimination.

The results of the identification and discrimination tasks, considered separately and together, suggest that subjects are using pre-aspiration as a cue to a phonological contrast. While the category boundary is not particularly sharp, we nonetheless see a cline in fortis identification followed by a plateau at ceiling as the duration of the pre-aspiration interval increases. Similarly, while there is not a single discrimination peak, there is a contiguous region of above-chance discrimination as well as a contiguous region of at-chance discrimination. Most importantly, this region of above-chance discrimination corresponds to the region surrounding the category boundary in identification, the region of at-

chance discrimination corresponds to the identification plateau, and there is a statistically significant relationship between how much adjacent steps differed in identification and how successful subjects were at distinguishing them.

5. Conclusion and further research

At the outset of this study, we mentioned the suggestion that pre-aspiration may be more difficult to perceive in comparison to other phenomena, such as post-aspiration, which may make it less useful as a cue to or a correlate of a contrast (Bladon 1986: 7, in Clayton 2010: 19; but also Kingston 1990 and Silverman 1995). We proposed that one way to test this claim is by looking into the pre-aspirating languages and their varieties and establish whether pre-aspiration serves as a correlate of and a cue to any relevant contrast. This paper examined Manchester English, for which pre-aspiration, and glottal reinforcement and replacement have been reported (e.g. Hejná and Scanlon 2015). We identified four main questions concerning the fortis–lenis contrast – we now return to these questions.

5.1. Can pre-aspiration function as an acoustic correlate of the fortis–lenis contrast in English?

Our case study of one speaker of Manchester English in lab speech style indicates that pre-aspiration and local breathiness are never found in the lenis series, and that they apply obligatorily in the fortis series in the word-medial position (e.g. *la**tt**er*) in the absolute sense (i.e. in 100% of the cases) and marginally also in the word-final position (e.g. *Ma**tt***). This suggests that voiceless pre-aspiration and local breathiness share the same function in the implementation of the fortis–lenis plosive contrast.

5.2. Does pre-aspiration also function as a perceptual cue?

Yes, native speakers of British English were able to use pre-aspiration as a cue to the fortis–lenis plosive contrast. As discussed in Section 4.2, pre-aspiration alone was sufficient to produce fortis identification in otherwise-ambiguous plosives, and the relationship between identification and discrimination suggests categorical perception indicative of a phonological contrast.

5.3. If pre-aspiration does function as a correlate of the fortis–lenis contrast, does this happen at the expense of other potential correlates?

The use of pre-aspiration as a correlate of the contrast does not seem to affect the number of other correlates employed. The duration of the preceding vowel (excluding voiceless pre-aspiration but including voiced breathiness; excluding glottalisation when this glottalisation is timed to occur immediately prior to the closure) is longer before lenis plosives than fortis plosives. The duration of the release, realised more as affrication rather than post-aspiration, is clearly longer in the fortis series medially, but importantly the distinction is not particularly clear-cut finally. We also looked into whether spirantisation may function as a possible correlate of the contrast; although spirantisation occurs more frequently in the fortis series, the difference is not particularly striking, and more data is needed to establish the extent to which it might function as a weak correlate of the contrast. Pre-aspiration and local breathiness are used *in addition to,* rather than in lieu of, more commonly described correlates of the fortis–lenis contrast.

5.4. Can glottalisation function as a correlate of the fortis–lenis contrast in English?

Glottalisation, and pre-glottalisation primarily, is found very consistently in the fortis series in the final position, where it applies near-obligatorily. When glottalisation is not found in the final position, we find pre-aspiration instead. This suggests that glottalisation and pre-aspiration block each other in the fortis context in Manchester English, which is in line with the results reported previously (Hejná and Scanlon 2015). Furthermore, glottalisation is a more reliable correlate finally than release duration.

5.5. Summary

Although VOT is often discussed as the correlate of and cue to the fortis–lenis plosive contrast in English, the majority of studies employing VOT target word-initial position. We conclude that, in non-initial positions, VOT alone cannot fully capture the phonetic implementation of the fortis–lenis contrast in the relevant varieties of British English (see also Vaux and Samuels 2005: 406), and that the timing of spread glottis is not necessarily limited to the release phase of

the plosive. Our study also suggests that the discussion of the fortis–lenis plosive contrast should consider its wide range of acoustic correlates. This study is limited to just one speaker of one variety of British English regarding production, and to only a handful of listeners who happen to be speakers of English varieties spoken in Northern England. It is important that further research approaches the role of pre-aspiration and glottalisation in more varieties of British English, both in production and perception. One possible consequence of this finding is that it is unclear whether [+Spread Glottis] is the appropriate feature to describe the fortis–lenis contrast (at least in those varieties of English that employ glottalisation as its correlate) if [SG] is to reflect the phonetic reality, rather than just serve as a convenient abstract label.

Our findings are further corroborated by the fact that pre-aspiration is a correlate of the contrast in *fricatives* in Scottish English (Gordeeva and Scobbie 2013), where /s/ is pre-aspirated, unlike /z/. The presence of pre-aspirated fortis fricatives in some English accents (see Section 2.1) suggests that they are specified for [SG], although it remains to be seen whether they trigger sonorant devoicing, like pre-aspirated plosives in Welsh English (Hejná 2016b). Our results raise the question of whether the fortis–lenis contrast should be represented by the same feature irrespective of the manner of articulation, i.e. whether the plosive and the fricative contrasts should be covered by a single feature – especially considering that, in some prosodic conditions, *constriction* of laryngeal structures may be just as important as the spreading of the glottis is in other prosodic conditions. This is not a new question (e.g. Vaux 1998; Vaux and Samuels 1995). What pre-aspiration and glottalisation do have in common is that they ensure that periodic voicing is blocked;[3] this shared behaviour is relevant, we argue, to their phonological representation.

Finally, the present study provides further evidence that pre-closure laryngeal properties can function as correlates and cues to phonological contrasts, thus adding to the pool of what has been seen as a dispreferred strategy (see e.g. Clayton 2009, 2010; Kingston 1990; Silverman 1995 for detailed discussions).

6. Acknowledgements

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[3] Although some types of glottalisation are periodic, they are nevertheless never followed by voicing during plosive closure.

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Appendix

The data consists of:

– Three repetitions of	*Please say mad again.*
	Please say lag again.
	Please say Matt again.
	Please say lab again.
	Please say lap again.
	Please say lack again.
– Three repetitions of	*Please say latter constantly.*
	Please say stagger constantly.

Please say ladder constantly.
Please say dabber constantly.
Please say stacker constantly.
Please say dapper constantly.

– Three repetitions of

I said lag, not lack.
I said lab, not lap.
I said dapper, not dabber.
I said Matt, not mad.
I said latter, not ladder.
I said mad, not Matt.
I said stagger, not stacker.
I said lap, not lab.
I said ladder, not latter.
I said stacker, not stagger.
I said lack, not lag.
I said dabber, not dapper.

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