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The role of syllable structure in external sandhi: An EPG study of vocalisation and retraction in word-final English /l/

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ABSTRACT

A pre-vocalic connected speech context is said to enable the resyllabification of word-final consonants into an onset, thus conditioning alternations. We present EPG data on English word-final /l/, measuring the extent of alveolar contact and the rate of vocalisation, the extent of dorsal retraction (representing "darkness"), and the timing of alveolar contact relative to dorsal retraction. Two dialects of British English are considered, namely Scottish Standard English and Southern Standard British English. Results are that /l/ alternation is systematic: the tongue tip contact of word-final /l/, quite categorically for some speakers, is more onset-like in pre-vocalic and more coda-like in pre-consonantal contexts. This alternation is not along the lines predicted by a segmental resyllabification account, however. First, the segmental identity of the following consonant (/b/ or /h/) may be as powerful a factor in conditioning the presence or absence of alveolar contact for some speakers. Second, glottalisation of lexically vowel-initial words regularly occurs, but does not seem to condition the appearance (or otherwise) of tongue tip contact. Third, the tongue dorsum remains retracted and does not adopt an onset-like form or timing even when /l/ is pre-vocalic. Thus categorical resyllabification of a word-final /l/ segment based on phonotactic acceptability is rejected as a mechanism controlling English L-sandhi in connected speech. Instead, we propose a gestural-episodic model, in which individual gestures display different levels of coherence in lexical syllable roles, while in connected speech, segmental sequences are influenced by similarity to well-rehearsed lexical sequences, if they exist.

1. Introduction

1.1. Allophonic variation in English /l/

It is generally agreed that English /l/ exhibits allophonic variation conditioned by its affiliation to categorically distinct syllable positions. In syllable onsets a "clearer" or "lighter" /l/ (neutral or palatalised) is found, while a "darker" /l/ is found in syllable codas (e.g., Boersma & Hayes, 2001; Chomsky & Halle, 1968; Cruttenden, 1994; Hayes, 2000; Jones, 1969; Ladefoged, 2001 and many others). Of course, other allophonic patterning occurs, some conditioned by prosody, some by non-syllabic contextual factors. In some dialects the syllabic light-dark allophony is quite extreme, while it may be more subtle in others (Carter, 2002). In Irish English for example, /l/ may tend towards the light end of the spectrum in both onset and coda (Jones, 1957), whereas it may be consistently rather dark even in the onset in Leeds or Glasgow (cf. e.g., Carter and Local, 2007), or in American English for some speakers (Ladefoged & Maddieson, 1996, 360f). Nevertheless, this allophony is seen as categorical, even if only because onset and coda are categorically distinct structurally.

In connected speech, it is commonplace to find that word-final consonants alternate when the following context varies. A word-final /l/ in a given lexical item is claimed to be light (and hence onset-like) when it occurs before a following vowel and dark (hence coda-like) in other contexts (e.g., Cruttenden, 1994; Ladefoged, 2001). The phonological literature suggests that the relevant conditioning contexts so closely match word-internal contexts that the standard syllabic phonotactics of the language may be held to be responsible, usually through a process of post-lexical "resyllabification" (e.g., Rubach (1996) and relatedly Gussenhoven (1986) and Kahn (1976)). Since syllable affiliation is, however, just one of a number of conditioning factors which may cause alternation of final /l/, its influence may be difficult to tease apart from other prosodic or coarticulatory ones. There remains no real agreement as to whether a word-final consonant in connected speech sometimes resembles a word-initial onset because it can become associated to an onsetless syllable in the following word, or because it is gesturally co-ordinated with a following vowel (and thus resembles true lexical onsets merely because they are always pre-vocalic). If the latter, then the

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concept of syllable structure is far less important in understanding connected speech variation of word-final consonants than is generally supposed, and it may be that in most cases it can be dispensed with altogether (Selkirk, 1984).

In this paper, we will examine the articulation of word-final, phrase-medial /l/ in detail, looking into how the following word-initial consonant (or lack of one) conditions allophony, specifically with the goal of understanding the extent to which connected speech forms are predicted by the putative syllable affiliation of the /l/. We will take a specifically articulatory perspective, which allows comparison with previous literature on inter-gestural timing and reduction in a direct way, as well as enabling examination of /l/ allophony even when no acoustic energy is present. We employ Electropalatography (EPG) which makes it possible to measure both linguo-alveolar and linguo-palatal contact kinematics.

1.2. *Articulation of /l/*

The light-dark allophony has its articulatory basis in the gestural composition of English /l/: The tongue tip constriction is accompanied by a (dialect-specific) dorsal gesture (termed variably pharyngealisation, velarisation or uvularisation). One of the most influential studies of how the magnitude and relative timing of these gestures lies at the heart of the syllable-based /l/-allophony is Sproat and Fujimura (1993), who focused on American English /l/ preceding a high front vowel (and /h/) across a variety of prosodic boundaries. Their articulatory study was not able to take dialectal variation into account, and they concluded that generally in a consonant with multiple gestures, the more constricted "consonantal" gesture – for /l/, this is the extension of the tongue tip up to the alveolar ridge – appears to be articulatorily weakened in coda relative to onset position (cf. also Giles & Moll, 1975). The less constricted or "vocalic" gesture, however, appears to be stronger in coda than in onset position. Further, in terms of inter-articulator timing, the intrinsically less constricted gesture (some form of dorsal retraction), occurs earlier relative to the consonantal gesture when the segment appears in the coda. Concomitant with these factors is an increase in the extent and duration of the acoustic correlates of the dorsal constriction, corresponding to the impressionistic percept of darkness.

Similar behaviour in English nasals helped to motivate the idea that there is a general process of gestural weakening of primary oral constrictions and differential timing in the coda relative to the onset (Browman & Goldstein, 1995, 2000; Giles & Moll, 1975; Krakow, 1993, 1999; Nam & Saltzman, 2003; Sproat & Fujimura, 1993). Subsequent work has argued that the four glides and liquids of English, which all have gestures of open approximation, may all pattern alike in connected speech, and that the liquids may indeed display some cross-linguistic tendencies (Gick, 2003; Gick, Campbell, Oh, & Tamburri-Watt, 2006). Note however that complexity and variation in their results led Gick et al. (2006, p. 68) to introduce a note of caution: they made the recommendation that the presence/absence of alveolar contact should be an important factor addressed in subsequent work, and they found that the relationship between early dorsal retraction and impressionistic darkness was "not clear" (cf. also Recasens (1996) for a very interesting discussion of the perception of /l/-darkness and vocalisation patterns in the Romance languages).

Indeed, while in syllable onset position English /l/ will typically display strong contact between the tongue tip or blade and the alveolar ridge, in coda position the alveolar constriction may be weakened (it is shorter and has weaker contact) and may result in loss of all contact, as shown in a number of articulatory studies (Giles & Moll, 1975; Hardcastle & Barry, 1989; Scobbie & Wrench, 2003; Wright, 1989). We will call such lack of contact "vocalisation", though neither that term nor the alternative "debuccalisation" is quite precisely what we mean. We certainly wish to avoid the implication that what we observe is identical to the impressionistic auditory judgement of /l/ vocalisation widely discussed in the sociolinguistic literature in which /l/ is said to be a vowel, phonetically or phonologically (Borowsky & Horvath, 1997; Johnson & Britain, 2007; Kerswill, 1995; Stuart-Smith, Timmins, & Tweedie, 2006; Tollfree, 1999; Trudgill, 1984). We presume that the observed tendencies for gestural weakening in certain contexts may potentially give rise to sociolinguistic variation and ultimately replace /l/ with a vowel or delete it (true phonological vocalisation), but we do not address the process here. We also do not claim that the primary alveolar place of articulation is lacking, which would be suggested by using the term debuccalisation, because even a categorical lack of contact as detected by EPG for /l/ need not be due to the complete loss of an alveolar gesture. Both vocalisation and gestural undershoot have been observed with EPG, but distinguishing between the two reliably requires a more subtle technique such as ultrasound along with phonological analysis (Wrench & Scobbie, 2003).

1.3. *Resyllabification*

1.3.1. *Ambisyllabicity and post-lexical resyllabification*

More popularly since Fudge (1969), Vennemann (1972), Hooper (1976), Levin (1985), and Kahn (1976), and as presaged by Haugen (1956), syllable structure has been seen an essential component of the phonological structure of words within Generative Phonology, and is typically assigned in a formal theory on the basis of the segments present in the lexical entry for a word (perhaps with some cognisance of the morphophonemic structure) at the point where the word can be said to leave the lexicon.

In citation forms a word-final consonant is pre-pausal, so in most views is necessarily syllabified into the coda.[1] A word-final consonant syllabified as a coda (or equivalent) may "re"syllabify in connected speech in that it may become associated with the following word's first syllable (Borowsky, 1986; Gussenhoven, 1986; Kahn, 1976; Rubach, 1996). Such an approach is generally assumed to add structure spanning the word boundary (a process called "liaison" by Gussenhoven, "onset ambisyllabicity" by Rubach, and "Rule V" by Kahn), without deleting the coda link.[2] Thus the word-final consonant is affiliated post-lexically to two adjacent syllables in two different words, and is "ambisyllabic". Jensen (2000) adopted the term ambisyllabification for this process, but, having now clarified what we mean, we will stick to the more common terminology. The post-lexical ambisyllabic configuration appears to straightforwardly permit the consonant to take on onset-like characteristics without losing its status as word-final coda, which may be important for phonological reasons in cases where its status as a coda is structurally crucial, e.g. for the assignment of stress or to satisfy minimal word requirements. Contrariwise, resyllabification has often been adopted as a mechanism to deal with more abstract phonological phenomena in which an abstract word-final consonant is posited, which due to extrametricality may not appear word-finally in citation forms but only when it fills an onset (e.g. in French

[1] Government Phonology provides a formal alternative in which word-final consonants are still special in a formalism with no codas, or syllable nodes (for an overview see Brockhaus, 1995).

[2] But see Halle and Mohanan (1985, p. 66): "Across words in phrases (which are concatenated at the post-lexical stratum) there is no resyllabification of *l* in English."

liaison). Phonetically, an ambisyllabic consonant may be expected to be intermediate in behaviour between onset and coda, or to vacillate between the two (see below).

Ambisyllabic consonants may also occur word-medially: indeed the structural innovation was proposed initially by Kahn (1976) to deal with situations in which consonants are presumed to have phonetic characteristics intermediate between onset and coda forms, to vary between onset-like or coda-like forms, to combine properties of both positions, or to exhibit behaviour atypical of plain onset or coda. As noted, ambisyllabicity of both types enables a consonant to satisfy phonotactic demands to be an onset *and* to close the preceding syllable, thus contributing to its metrical heaviness. See Jensen (2000) for a review which rejects the concept in favour of an alternative proposal, while accepting much of the evidence put forward in previous phonological descriptions. We will have no more to add here to the topic of word-internal ambisyllabicity or variation in /l/ within words. Nor will we be able to address the weak syllables of *apple* or *little*, where /l/ is often claimed to be syllabic (Barry, 2000; Scobbie & Wrench, 2003; Toft, 2002). Suffice it to say that ambisyllabicity in such forms is more complex if the final /l/ is regarded as being phonologically in the nucleus rather than in the coda of a metrically weak syllable.

Despite the widespread belief in the phonetic and phonological literature that changes that consonants undergo at word boundaries may be explained on the basis of the structural phonological association of the coda consonant to the onset position, attempts to give an empirical basis to these theoretical concepts have proven elusive, and literature is comparatively scarce in this respect: Turk (1994), for instance, found that English ambisyllabic labials such as occur in the words *leper* or *caliper* pattern kinematically predominantly with final stops, and do not show the intermediate properties between onset and coda labials predicted by ambisyllabicity. Gick's (2003) /l/ data on a single subject, however, provide some evidence for an intermediate tongue tip height in ambisyllabic position compared to onset and coda position. In a later cross-linguistic study which looked at word-final /l/ (Gick et al., 2006), the English results were again rather ambiguous, and given its relevance here, it is worth looking at this study in some detail.

The English materials in this study were designed to give different syllable affiliations to /l/, as follows: *fay lame* (onset) vs. *fail aim* (ambisyllabic) vs. *fail maim* (coda). In Fig. 2 of Gick et al. (2006), graphs are presented for the average TT (tip) and TD (dorsum) displacement for two speakers of Western Canadian English based on ultrasound data. These show that the extent of TD retraction is largely unaffected by syllabification for speaker 1: from the previous vowel there is approximately a 1 cm relative retraction to an absolute (arbitrary) displacement of 2.8 cm in the onset, to 3.1 cm in the ambisyllabic context, and to 2.9 cm in the coda. Speaker 2 shows about 0.4 cm retraction to a 4.4 cm displacement in the onset, about 0.5 cm retraction to 3 cm in the ambisyllabic condition, and about 0.5 cm retraction to 3.9 cm in coda. In neither speaker does the extent of TD retraction appear to be intermediate in the ambisyllabic case. TT displacement appears similarly unsupportive of ambisyllabicity. Relative displacement is comparable in all conditions (0.2 cm for speaker 1 and 0.4 cm for speaker 2). In absolute terms, Speaker 1's ambisyllabic /l/ has a greater absolute TT displacement than onset, which in turn is greater than the coda (about 0.25 cm in each case), while Speaker 2's onset TT is displaced about 0.6 cm more than the coda, with ambisyllabic TT at the opposite end of the continuum this time, with further reduction of displacement than the coda by approximately 0.6 cm.

It is not clear which if any of the observations above are statistically significant, for the paper presents and discusses only timing results based on these displacements: "Both subjects exhibited a significant positive lag in pre-vocalic [i.e. onset] position, no significant lag in intervocalic [i.e. ambisyllabic] position, and a significant negative lag in post-vocalic [i.e. coda] position" (Gick et al., 2006, p. 59). The mean difference in timing is, roughly, that the TD displacement before the TT maximum is 22.5 ms advanced in the coda relative to the ambisyllabic case (where the displacements are approximately simultaneous) and 55 ms delayed past the TT maximum in the onset case. The 80 ms or so difference between conditions thus provides some support for resyllabification of /l/. Even though the word-final consonant exhibits different characteristic timing patterns in different contexts (cf. also Sproat & Fujimura, 1993), the role of the syllable in such variation needs to be examined more closely.

Impressionistic studies, which are far more common than articulatory ones, certainly show that the quality of word-final ambisyllabic /l/ varies, and does so due to a wide range of factors. There appears a strong potential for dialectal variation: /l/ in an ambisyllabic context may be light in quality and consonantal, for example in Essex (Johnson & Britain, 2007), or vocalised and /w/-like, for example in London (Tollfree, 1999). Further conditioning factors such as style, prosodic context and speaking rate are highly relevant, and methodological issues in data collection as well as definitions of vocalisation and darkness clearly need to be taken into account in evaluating the literature. Thus it is unclear when looking at different studies reporting intermediate behaviour or inter-speaker variation for an ambisyllabic consonant within a dialect, what the variation really amounts to, nor to what it should be attributed.

1.3.2. The role of phonotactics in blocking resyllabification

Despite considerable variation in impressionistic judgements of /l/ darkness, both phoneticians and phonologists generally agree that, like syllabification itself, resyllabification and ambisyllabification can occur before a following segment only if the resulting onset is phonotactically permissible (Gussenhoven & Jacobs, 2005, p. 152; Sproat & Fujimura, 1993, p. 296). Though informally acknowledged and necessary for many analyses, this assumption has had surprisingly little explicit critical appraisal in the literature, especially when more complex phonotactic patterns are involved. Krakow (1999) is an exception, and in her overview of articulatory correlates of syllable structure, she states that resyllabification may still be expected in a pre-consonantal context if the resulting cluster is phonotactically legal. See also the treatment of intervocalic consonant clusters in the YorkTalk speech synthesis programme (Coleman, 1994, pp. 314–315).

Selkirk (1984) distinguishes word-internal resyllabification, respecting the phonotactics of the language and operating in the lexical morphophonology, from more general resyllabification. She says: "On higher domains within the word… resyllabification does not follow the BSC [basic syllable composition] rules, but only certain restricted universal principles, such as the principle that makes a coda consonant the onset of a following onsetless syllable. And on domains higher than the word, it is debatable whether any resyllabification takes place at all" (p. 25). This debate, interestingly, has never really been taken up in subsequent literature, but the general practice seems to lie in the assumption that any onsets created by resyllabification in connected speech have to be phonotactically well-formed.

Yet there is some evidence in the literature that suggests that the variability of L-sandhi may be greater than anticipated from a resyllabification perspective. Specifically, anecdotal evidence reported in the studies of Recasens (1996) and Scobbie and Wrench (2003), suggest that the behaviour of word-final /l/ is not globally conditioned by a following consonantal versus vocalic context. Rather, the individual identity of the following consonant may play a role. The articulatory study of word-final English /l/ by Scobbie and Wrench (2003) provides a new angle on the issue because they found systematic and categorical vocalisation in all their speakers. Vocalisation was defined as complete loss of contact with the EPG palate at the alveolar ridge. All speakers exhibited L-sandhi, so that word-final /l/ was vocalised in (some) coda contexts and consonantal when pre-vocalic, a finding further supported by analysis of simultaneously recorded EMA data (Wrench, 2000). What was particularly interesting was the variation in the coda contexts triggering vocalisation: word-final /l/ was almost always vocalised phrase-medially before a labial consonant whereas pre-pausally, only four speakers vocalised. The authors also observed in passing, and on the basis of only a handful of tokens, that "final /l/ was particularly resistant to vocalisation before word-initial /h/" (Scobbie & Wrench, 2003, p. 1874) compared to the word-initial labial consonants /p, b, f, v, m/. This apparent difference in behaviour between a following /h/ and labial consonant is surprising from a phonotactic perspective: /l/ cannot occur before any another consonant as part of an initial consonant cluster in English. Whatever the internal featural specification of /h/ or /b/, each has a "root" node and fills an equivalent place in structure. A resyllabification-based account of L-sandhi predicts that word-final /l/ should behave alike in all pre-consonantal contexts, whether the speaker typically exhibits vocalisation or not, and that resyllabification to onset will only be possible before a vowel. Before any consonant, including word-initial /h/, a word-final /l/ is "necessarily syllable-final since /l/ cannot occur before another consonant as part of an initial consonant cluster in English and there is therefore no chance of resyllabification" (Sproat & Fujimura, 1993, p. 296).

Here it is worth keeping a methodological point in mind: the phonetic effects of word-final ambisyllabicity are usually assumed to be revealed through the study of all word-final consonants in a post-lexically pre-vocalic context.[3] Note that it is not possible to construct exactly balanced materials in which an onset, a coda, and an ambisyllabic consonant can be compared, however. To ensure that a word-final consonant is indeed a coda, it cannot be structurally intervocalic, but must appear before a consonant which blocks resyllabification. This experimental confound is almost always downplayed: if an intervocalic word-final /l/ (Vl#V) in connected speech is intermediate in behaviour when compared to an intervocalic word-initial /l/ (V#lV) and a pre-consonantal word-final /l/ (Vl#CV), then this is directly taken as evidence that Vl#V is structurally ambisyllabic (Gick, 2003; Gick et al., 2006), even though it might merely be what is typical of a word-final pre-vocalic *coda*. Our point is that any onset-like characteristics of a word-final consonant might be due exclusively to linear coarticulation in a pre-vocalic context, while its coda-like characteristics would be due to it being a coda (cf. also Bladon and Al-Bamerni (1976) on the coarticulatory properties of clear and dark l). In any case, we can expect to find token-by-token variation in the relative balance of these characteristics, depending on rate, stress, lexical frequency, discourse structure, prosody and so on, which will affect the strength of juncture and amount of overlap between a final /l/ and the following word.

1.3.3. *Word-initial glottalisation*

In a pre-vocalic context, though there are no phonotactic impediments, resyllabification to onset before a vowel does not always appear to occur, despite tendencies to maximize onsets. Anecdotal observation (e.g., Cruttenden, 1994, p. 183) suggests that when resyllabification does not occur, phonetic glottalisation may be observed around the juncture. Analytically, we could propose that there is an empty onset in the following vowel-initial word which can be filled by a glottal stop. A phonological analysis of this would be straightforward if the glottal were a consonant phoneme of English, as it would fill the onset and block resyllabification like any other consonant. But no phonological analysis of English we are aware of has taken this approach. A more plausible phonological alternative is that glottalisation is the phonetic interpretation of empty onset in surface structure (Keating, 1988; Pierrehumbert, 1995). In any case, we can be sure that */lʔ/ is a forteriori not a possible onset, because English has no /ʔ/. As noted, the more likely alternative is that an empty onset is present, with glottalisation being a phonetic interpretation of unfilled structure. In this model, glottalisation does not block anything, but is also, like the lack of coarticulation, a reflex of a strong boundary.

Even so, explicit reference to blocking of resyllabification by glottal stop does occur – for English and cross-linguistically – both in phonology and phonetics, as argued among others by Jongenburger and Heuven (1991) ("resyllabification/hiatus deletion and glottal stop insertion are therefore mutually exclusive choices", p. 102) and Gick et al. (2006, p. 54); "vowel-initial words … had a strong glottal onset, preventing resyllabification"). However, the phonological status of word-initial [ʔ] or vocal creak as an aspect of word-initial vowel phonemes is deeply problematic, and this issue has received less attention than it requires.

1.4. *Overview of this paper*

In examining L-sandhi with EPG, a major goal is to follow the suggestion of Scobbie and Wrench (2003) and investigate whether there are systematic differences in the vocalisation of coda /l/ as a function of the identity of a following consonant (cf. also Recasens, 1996). Specifically we will investigate the non-lingual consonants /h/ and /b/ because neither of these has a phonological lingual specification. Methodologically, there is therefore no ambiguity about the meaning of any linguo-palatal contact detected, for there will be no lingual coarticulation between the /l/ and the following labial. Thus any differences in contact pattern observed can be assumed to be due to structural factors alone.

We will also take note of how vocalisation interacts with juncture glottalisation when /l/ precedes a word-initial vowel, if and when such glottals spontaneously occur. We further examine whether resyllabification affects both gestures of the /l/ equally or whether the anterior and posterior gestures behave differently in the pre-vocalic context (i.e., the context that may be ambisyllabic, where we use the term in a theory-neutral manner). We also investigate whether the degree of retraction in coda position is systematically related to the degree to which we observe vocalisation for individual speakers in different contexts. Lastly, our study includes speakers from two dialect groups that differ in /l/ allophony: Southern Standard British English is widely described as having the "classic" distribution of light /l/ in onset and dark /l/ in coda, while Scottish Standard English is said, roughly, to have dark /l/ in both syllable positions (Stuart-Smith et al., 2006).

2. Method

2.1. *Data recording*

The hardware set-up involved capture of electropalatographic (EPG) data sampled at 200 Hz with an Articulate Instruments

[3] More unusually, the word-final consonant may precede a consonant with which it can make an onset cluster, but this is not a possibility here because English has no legal /lC/ onset clusters.

Table 1
Experimental conditions.

Condition		n	Part of prompt sentences
Onset	[pi # li]	16	pee Lima's and Rio's… pee leeward in …
Gem	[pil # li]	8	peel lemurs for/in …
Ambi	[pil # i]	24	peel Eve an/any … peel Eva some … peel evening oil/wear …
Coda_b	[pil # bi]	16	peel beavers in/on … peel BBC …
Coda_h	[pil # hi]	24	peel heaving and retching … peel heaps of … peel haematite stickers …

multichannel WinEPG system, with simultaneous recording of acoustic data (sampled at 44.1 kHz) in a sound-treated studio at Queen Margaret University. The software used for data collection and analysis was Articulate Assistant Advanced^{TM} (AAA) v2.04–v2.06 (Wrench, 2008).

2.2. Participants and procedure

The speakers analysed here comprise a convenience sample of academic staff at Queen Margaret University in the possession of an individually-fitted EPG palate with 62 electrodes (cf. McLeod and Singh (2008) and Stone (2006) for an introductory overview). All are native speakers of English, and their phonological systems fall into two broad dialect groups, Standard Southern British English (SSBE, "E" subjects) and Scottish-accented Standard English (SSE, "S" subjects), with five speakers in each group. Impressionistically, all have typical phonological systems for their accents.

All of our subjects were very experienced in speaking with an EPG palate; they also wore their EPG palates for at least half an hour before the recording time which was judged sufficient (for naïve users see MacAuliffe, Lin, Robb, & Murdoch, 2008). The stimulus sentences, with which the subject had previously been familiarised, were presented on a screen one at a time.[4] Sentences were presented in four pseudo-randomised blocks, the same for each subject, each block containing two slightly different instances of each prompt sentence, giving either 8, 16, or 24 instances of each condition (see Table 1) in total.

2.3. Materials

The full set of target conditions was /i#li/, /il#i/, /il#bi/, /il#hi/, /il#li/ (Table 1). The target sentences all put /l/ or /lC/ into a /C_{labial}i___iC_{labial}/ context where the second /i/ vowel was in a lexically stressed syllable in an accented word and the first belonged to either *pee* or *peel*.[5] There was no fixed carrier phrase (see below), but there was a consistent prior context, namely *Can we*, with an unstressed pronoun, and the syllable following the second C_{labial} was always unstressed.

Singleton /l/ was word-initial in the Onset condition, word-final in the Ambi (potentially ambisyllabic) and both coda conditions, Coda_h and Coda_b. It is the presence or not of a following word-initial vowel that determines whether a word-final /l/ is regarded as being potentially resyllabifiable. Otherwise

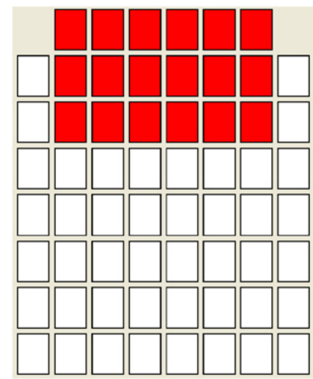

Fig. 1. Schematic representation of an EPG palate showing the 18 contacts identified as the "L-zone" shaded in dark.

the /l/ is a coda because a consonant (/h/ or /b/) follows. The Gem context has two phonological /l/ in sequence.

As noted above, there was no fixed carrier phase. Indeed there were two variants of Table 1's eleven target sentences, making 22 target sentences in all (Appendix A). The sentences were repeated in four differently randomised blocks, rendering 88 target sentences for analysis per speaker. Technical faults halted data collection from S1 early, after 3 blocks and 3 items (n=69), and rendered 7 tokens from S2 unusable (n=81). EPG data from S5 are unusable for analysis of extent of alveolar contact and retraction due to a different palate design, but are suitable for distinguishing consonantal from vocalised tokens, although, as noted above he, like S1, was aware of the purpose of the experiment. For E2, a defective electrode in the second back row of the palate showed contact all of the time and was thus not taken into consideration in the retraction analysis. See Appendices C and D for the actual numbers of tokens that were analysable for each of the measures outlined below.

The variation in carrier phrase was intended to distract speakers and to draw phrasal stress to a position late in the sentence away from the /l/ (e.g. a block would contain both *Can we peel Eva some fruit from the basket?* and *Can we peel Eva some fruit from the shops?*), which consistently attracts phrasal stress to the new information at the end. The sentences were semantically coherent and more vivid than is normal, and these tactics were successful in distracting the linguistically-sophisticated subjects and hiding the purpose of the experiment. These materials were randomly interspersed with 34 structurally very different sentences for another experiment which acted as fillers.

2.4. Analysis

For all data a temporal "L-interval"[6] was annotated on the basis of the acoustics, beginning at the oral release of the

[4] Most subjects were naïve as to the research questions addressed by the experiment, but S1 (Scobbie) and S5 (Wrench) were fully aware of the design (cf. Scobbie, Pouplier, & Wrench, 2007). In addition, as is noted elsewhere, there were technical difficulties which terminated S1's data collection session early and render S5 inappropriate for quantitative analysis of palate contact. We therefore treat the results of these two participants with some caution, in cases where their data is included.

[5] Two further sentences beginning "Can we be leaving" with its unstressed auxiliary were discarded.

[6] For readability we use capital "L" but lower case "i" in terminology associated with the acoustic/EPG regions used to analyse /l/ and /i/.

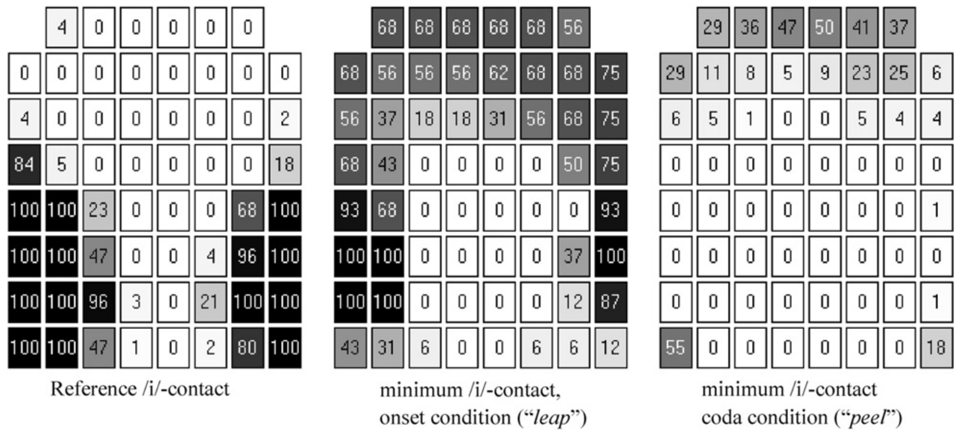

Fig. 2. Example from speaker E1 of retraction. Left: Reference i-zone identified on the basis of maximum contact in the back four rows during the L-interval, averaged across all conditions. Middle: Average frame of minimum i-zone contact during the L-interval for the onset condition, showing slight loss of palatal contact. Right: Average frame of minimum i-zone contact during the L-interval for the coda conditions showing lack of palatalisation as well as reduced alveolar contact. (Note that for this illustration, the average of the coda conditions comprises all tokens, vocalised and non-vocalised.) The numbers in each cell are the % of tokens with a contact in that cell.

preceding labial stop in the carrier phrase (/p/ from *pee* or *peel*), and including its aspiration, the /i/ of that word, the /l/, the following /b/ or /h/ or /l/ if present, and all of the /i/ of the second word up to the start of the following labial consonant, for example the onset of closure of the /p/ of *heaps*. In the case of /w/ in *leeward*, the boundary was imposed when F2 started to fall rapidly.

Alveolar contact during the L-interval was defined by reference to a cross-speaker spatial "L-zone" of 18 EPG contacts in the three front rows of the palate (cf. Fig. 1). If any contact at all occurred in this area during the L-interval, the token itself was automatically coded as "consonantal" by the software, enabling us to detect contact against a broad mid-sagittal area of the alveolar ridge.[7]

For each consonantal token, the frame of maximum L-zone contact was also identified automatically using AAA scripts. This frame constituted the measure "cons-L", defined as the number of L-zone electrodes contacted, ranging from 0 in a vocalised token up to 18 for all contacts simultaneously contacted. It was used for an analysis of the degree i.e. strength of contact. Due to the individual differences in the amount of consonantal contact in the L-zone in onsets, the data were normalised relative to the average number of consonantal contacts in the onset condition, which was fixed at 100% for each speaker. The mean number of contacts varied from 7 or 8 (S1 and S4) to 16 (E1 and E3). The normalised % of contact of each individual token relative to the average onset was then easy to calculate for each individual token.

With EPG we can indirectly assess the degree of tongue body retraction characteristic for English /l/ which leads to an auditory impression of darkness. The high front vowel /i/ exhibits extensive lateral EPG contact extending backwards from the palatal region of the palate (Yuen, Lee, & Gibbon, 2007). We chose a flanking /i/ vowel in the materials in order to observe the degree of retraction during the L-interval on the basis of the reduction of posterior contact. Given the individual differences in /i/ which we and Yuen et al. observed, we decided to use a reference pattern [i] individually for each speaker (Fig. 2) in order to define a region from which tongue-palate contact will be increasingly absent as the size of dorsal retraction and lowering increases.

To find the reference frame, the frame of maximum contact in the back four rows of the palate during the L-interval was identified in each token ($n=88$) and averaged. The pattern of all 62 contacts of this average palatogram was taken to be the reference for /i/ on a speaker-specific basis (cf. Byrd, Flemming, Mueller, & Tan, 1995). Appendix B gives the actual reference pattern for each participant.

Using this information (with percentages rounded to the nearest multiple of 10) a speaker-specific palate weighting, an "i-zone", was used to create a continuously-changing analysis value (Wrench, 2008).[8] In most conditions the value showed coarticulatory decrease in palatal contact as the [i] changed to a dark [l], then increased again for the second [i] (Fig. 3a). Light /l/ often showed only a small amount of retraction. Fig. 3b exemplifies the retraction pattern for the fake geminate condition. We quantified the extent of /l/-related retraction by automatically finding the frame during the L-interval which exhibited the lowest percentage of contact in the reference i-zone. The lower the minimum value, the stronger the dorsal retraction and the impressionistic darkness.[9] Simple reduction of contact in

[7] All data were checked when each individual token was being annotated for the timing analysis. In six cases a small amount of contact was found only at the very beginning or end of the L-interval, due for example to coarticulation with a sound outside the L-interval, and so a hand correction was made to treat these tokens as vocalic. We are certain the contact was not conditioned by the /l/. Further hand correction would have been necessary had we not excluded columns 1 and 8 from the L-zone: anterior contact near the premolars or canines in the absence of any central contact can be present as part of the production of [i], and could be interpreted to mean a consonantal [l] is present. This is also why we only examine /l/ before labials, rather than lingual sounds, when the patterns of vocalisation may be different, and the data more ambiguous (Hardcastle & Barry, 1989). A few cases had contacts centrally in the fourth row of the palate which we would attribute to /l/, but since all had contact in the L-zone, this affects only the analysis of contact strength, and some fourth row contacts are attributable to palatalisation (e.g. the middle panel of Fig. 2). We should note also that there is a clear sequence of abutting consonantal word-final /l/ and word-initial /l/ in the "Gem" fake geminate condition in three tokens from E4, but otherwise the sequence is apparently smoothed and coarticulated into one event.

[8] Speaker-specific i-zones were used because there is an external standard to compare the darkness of /l/ to, namely a speakers' average [i] vowel. Contact against the palate reduces during dark /l/, but additional anterior contacts may appear due to an alveolar gesture, hence only contact within the i-zone is measured. A cross-speaker zone based on average [i] and a stylised approximation to [i] contact give highly similar results, but a speaker-specific zone should be used in preference. For the L-zone, a large alveolar area common to all speakers was used to let us observe tongue contact even when it is in slightly different place to the average onset [l]. Alveolar contact could then be normalised to the number (but not location) of alveolar contacts in the onset.

[9] This assumption was supported by a sample of onset and coda tokens which were impressionistically transcribed, but note the articulatory/acoustic relationship is not direct and cannot be addressed in more detail here.

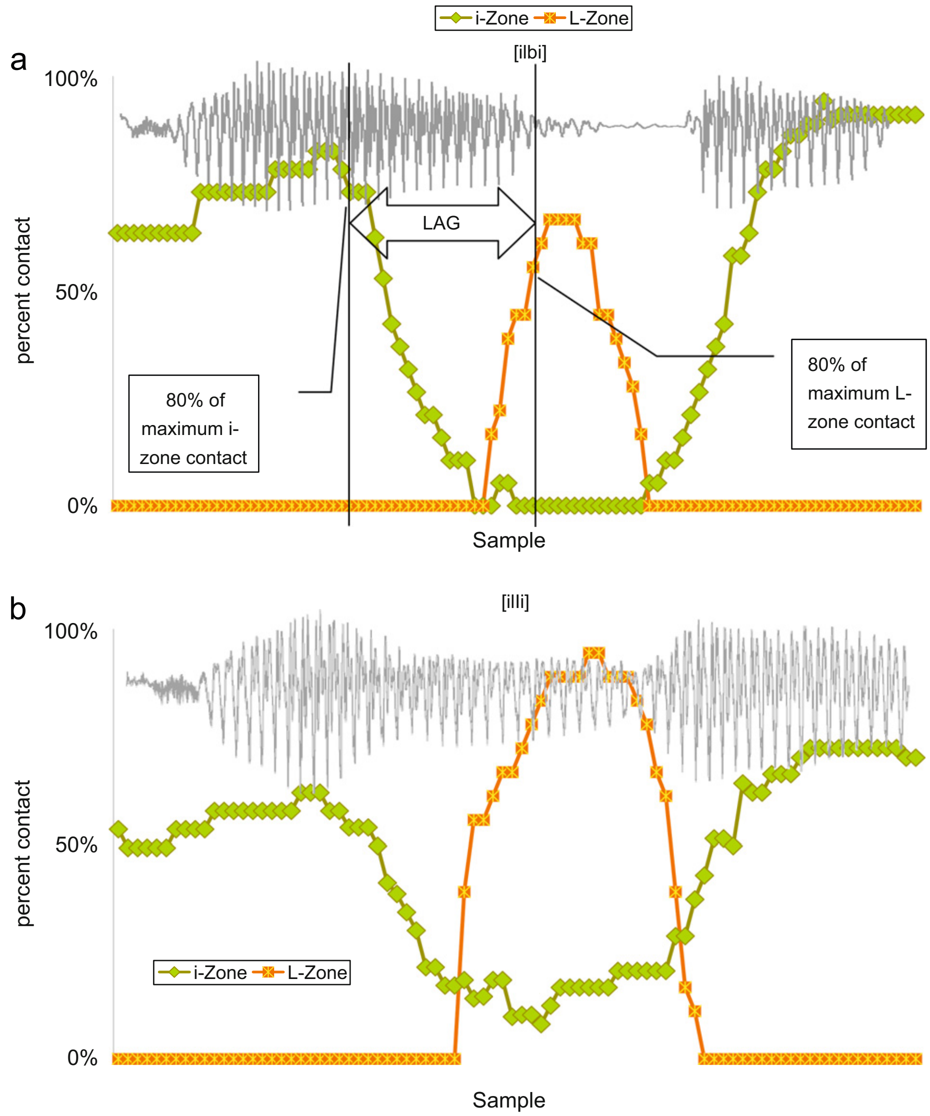

Fig. 3. (a) Time course of i-zone and L-zone contact for the [ilbi] portion of an utterance of *peel BBC* as spoken by subject E1. The 80% contact thresholds chosen as landmarks to measure inter-gestural timing are indicated. (b) Time course of i-zone and L-zone contact for the [illi] portion of an utterance of *peel lemurs* as spoken by subject E1.

this zone turned out to be the best measure: examining the centre of gravity of contact in the i-zone was less sensitive and more errorful. This tallies with Sproat and Fujimura's (1993) observation that there is no evidence of raising of the dorsum towards the velum for dark [l] in a front vowel context, but rather, the tongue lowers, and in the context of /i/, linguo-palatal contact reduces in extent.

This measure of /l/-retraction further enabled us to assess the timing relationship between the coronal and dorsal gestures of the /l/. Such an analysis is, however, faced with the problem that EPG renders rather different information about the time course of the two articulatory events: While information about the kinematics of the tongue tip gesture is detectable only near the attainment of target, when the tongue tip or blade has raised sufficiently to make some contact with the hard palate, the very beginning of the tongue dorsum retraction gesture will be visible, since the tongue is in contact with the EPG palate for [i] already. Moreover, for cases of tongue tip gestural undershoot with no alveolar contact at all, no timing measures can be made. In measurement of the tongue dorsum gesture, on the other hand, timing analysis is complicated by the floor effect which occurs if the EPG contact reaches zero or another stable minimal value in the i-zone. The timing of the attainment of the greatest extent of the retraction gesture can only be estimated.

Because we cannot necessarily see the beginning and end point of both kinematic events, a different type of landmark was chosen for each, but one which would be detectable reliably across tokens. We measured the time lag between the *beginning* of the retraction gesture and the *achievement* of target for the coronal gesture. Fig. 3a exemplifies these fixed landmarks in a token of coda /l/.

Using an automatic AAA script, the beginning of the retraction movement was defined as the time point at which i-zone contact drops below 80% of the preceding maximum contact for that individual token. The achievement of the coronal target was analogously defined as the time point at which the L-zone contact reaches 80% of its local maximum. These landmarks and the 200 Hz sample rate enable a coherent and detailed investigation of inter-articulator timing which can be compared to previous studies (e.g., Gick et al. (2006) who compare the temporal midpoints of the gesture but who use video-based ultrasound with a 30 Hz sampling rate, in which timing measurement is far less reliable).

If there was a negligible amount of retraction, that is, if the minimum i-zone contact was never below 80% of the preceding maximum or if there was no alveolar contact, then the token provided no timing measure (see Appendix D for details). With such small retractions, while timing is moot, the (small) extent of maximum retraction was still analysed.

3. Results and discussion

3.1. *Alveolar contact*

3.1.1. *Binary analysis*

Our first analysis contrasts onset against coda /l/ in terms of alveolar L-zone contact. Fig. 4 shows the results of a binary analysis of the presence or absence of contact in the L-zone during the L-interval. 100% of tokens display L-zone contact in word-initial onset position. This is as expected on the basis of previous articulatory work on /l/ and validates the selection of our L-zone. We also note that the fake geminate condition displays contact for all tokens, presumably due to the presence of the onset /l/. The three non-geminate conditions with word-final /l/ differ considerably between speakers. All Scottish speakers except S5 vocalise word-final /l/, irrespective of the following context—vowel, /b/ or /h/. For S5 and E2, /l/ is consonantal in all conditions and two other English speakers (E1, E4) rarely vocalise. Most interestingly, the final two English speakers (E3, E5) vocalise /l/ in one coda condition, namely before /b/, but not in the other, before /h/, confirming the phenomenon observed by Scobbie and Wrench (2003). None of the speakers show the reverse pattern, vocalising before /h/ but not before /b/. Before a word-initial vowel, the ambisyllabic condition, the data show a more continuous range of inter-subject variability. While two Scots (S4 and S2) vocalise most if not all of the time, the vacillating S1 and S3 show contact for roughly 50–60% of tokens. None of the English speakers vocalise in this condition, and nor does S5. The data were arcsine transformed and subjected to an ANOVA with the between-subjects factor Dialect and the within subjects factor Context with the four levels onset, ambisyllabic, coda_h, coda_b. Since onset and geminate were both at 100% for all speakers, only onset was included in the statistical evaluation. Both main effects were significant, as was the interaction (Dialect: $F(1,8)=87.75$; $p<0.001$; Context: $F(3,24)=16.684$; $p<0.001$; Dialect × Context: $F(3,24)=3.449$; $p=0.032$). For the comparisons of theoretical interest, two-tailed, paired-samples post-hoc *t*-tests were conducted to compare the ambisyllabic to the coda_h and coda_b conditions. While the ambisyllabic condition differed significantly from the coda_b condition ($t(9)=-3.331$, $p=0.009$), the difference to the coda_h condition was not significant ($t(9)=2.001$, $p=0.076$).

Overall, these results are unexpected from a resyllabification perspective, which predicts the two word-initial consonants /h/ and /b/ will behave alike, and /l/ before vowels to behave either similarly to onsets or display hybrid onset and coda properties. Only S1 (the first author) and S3 show the expected alternations. For these two speakers, the consonantal coda conditions vocalisation, and the vowel condition is intermediate between the onset and coda (with about 60% of tokens showing contact). S1 is known to have a particularly strong vocalisation of coda /l/ with the tongue blade pulling downwards in coda contexts (Wrench and Scobbie, 2003). The English speakers and S5 (who was aware of the experimental design) show an expected pattern pre-vocalically (namely onset-like behaviour of /l/), but they either do not

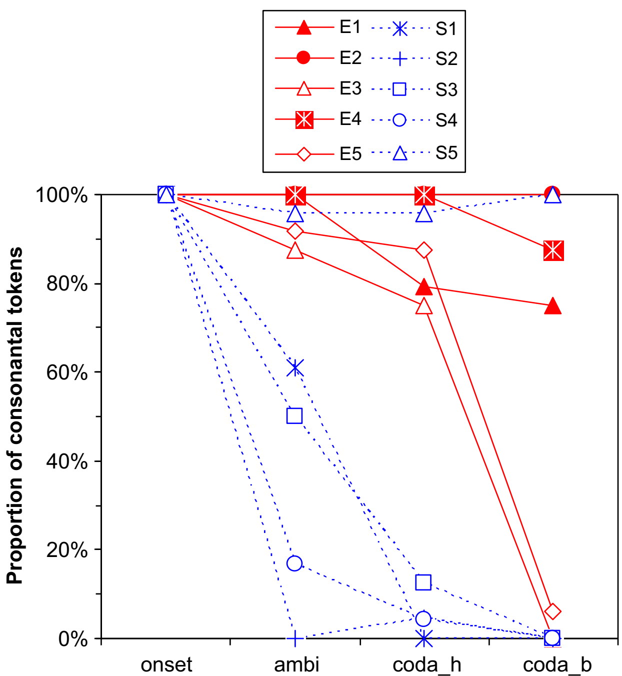

Fig. 4. Binary contact analysis showing percentage of tokens with any contact in L-zone for all speakers.

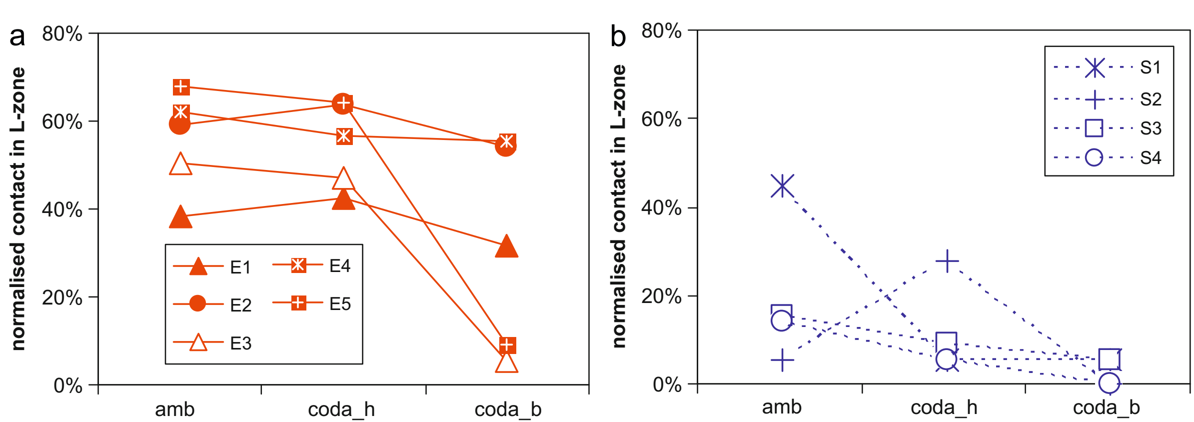

Fig. 5. Mean L-zone contact extent for consonantal tokens in ambisyllabic and two coda conditions relative to each individual's onset for (a) English and (b) Scottish speakers.

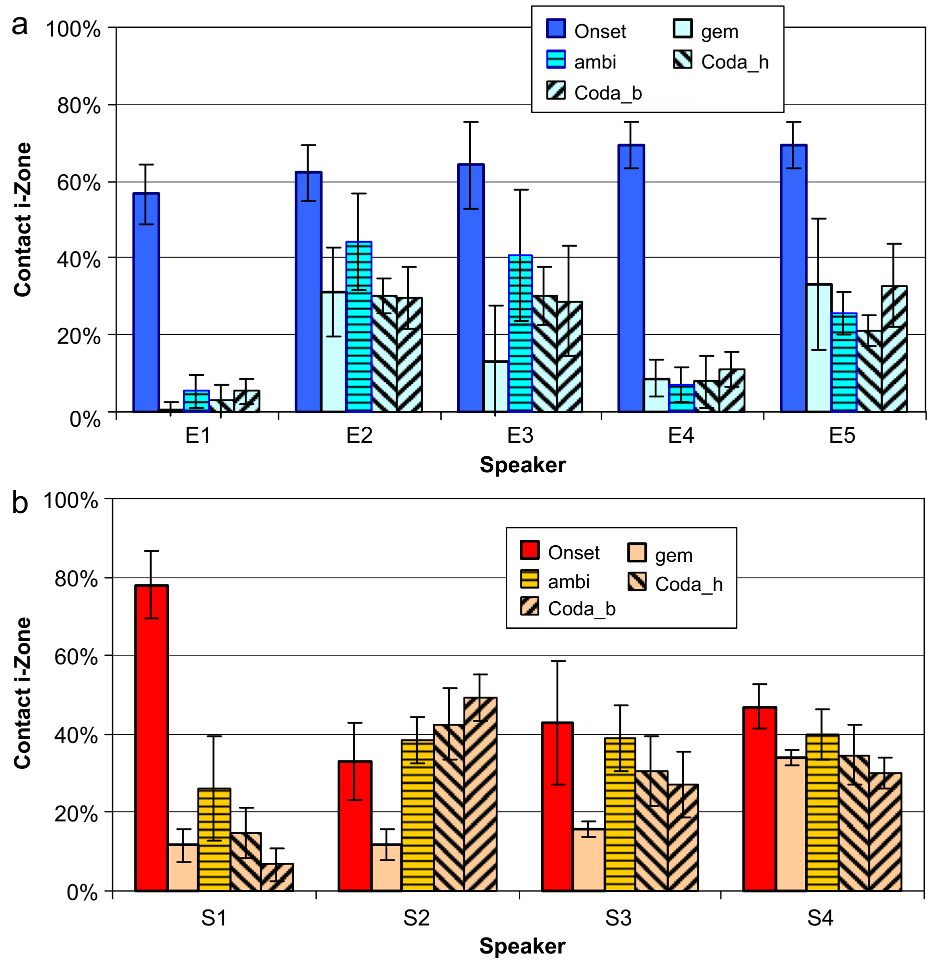

Fig. 6. Percent i-zone contact as a measure of /l/ retraction shown separately for English and Scottish speakers. The lower the value is, the greater the retraction. (a) English speakers (b) Scottish speakers. Whiskers indicate 1 SD in each direction.

differentiate between the vowel and the consonant conditions (E1, E2, E4, S5), or, they differentiate between pre-vocalic and /h/ versus following /b/ (E3, E5).

3.1.2. *Gradient degree of alveolar contact*

We turn now to the s*trength* of each alveolar gesture, normalising each speaker relative to the strength (number of contacts) of their own onset condition, and focussing on comparisons between the ambisyllabic context and the two coda contexts. In Wilcoxon tests carried out separately for English and Scottish speakers, English ambisyllabic /l/ was different to coda_b /l/ (p=0.04), but it is clear that this is due to the two speakers E3 and E5 (Fig. 5a). The same comparison for Scottish speakers nearly reaches significance (p=0.07), where it is S1 that causes the apparent distinction.[10] Overall it appears that the pattern of groups (Scottish vs. English, and E3, E5 vs. the other English) seen in the binary contact analysis (Fig. 4) is echoed in the distribution of greater versus lesser contact for consonantal tokens (Fig. 5).

Two other trends merit mention. First, for all speakers, *consonantal* codas are substantially weaker than their onsets, and it appears that Scottish speakers have weaker consonantal contact than the English ones. Second (not shown in Fig. 5), the fake geminate condition may display an even stronger contact than the onset, especially for Scottish speakers, even though Scots vocalise coda /l/ normally. And finally, stepping back from the normalised values to raw values, it appears from Appendix C that Scottish speakers generally have fewer contacts in the L-zone (around 11) than English ones (around 14). A *t*-test on pooled onsets confirms the dialect difference ($t(137)=5.66$, $p<0.0001$).

3.2. *Dorsal retraction*

We investigated retraction in /l/ on the basis of the loss of i-zone contact during the L-interval, as detailed above. Fig. 6 shows the different degrees of retraction on a by-speaker basis, separately for Scottish and English speakers. Recall that the lower the percent value, the lower the linguo-palatal contact in the i-zone, and hence the greater the retraction (and/or lowering) of the tongue dorsum.

Overall, the onset condition is least retracted, while the fake geminate condition is most retracted. The ambisyllabic condition generally patterns with the other coda conditions, although it may be slightly less retracted than coda_h or coda_b.

Given the nature of these articulatory measures, a repeated measures ANOVA with a within subjects factor Context (five levels: onset, geminate, ambisyllabic, coda_h, coda_b), and a between-subjects factor Dialect was performed, and it was

[10] See Scobbie, Pouplier, and Wrench (2007) for more discussion and Appendix C for the means and standard deviations of raw degree of contact for each speaker, calculated excluding all zero contacts. In the discussion here we exclude S5, due to his different palate design.

significant for both main effects, and the interaction was not significant. (Using the Greenhouse-Geisser correction for violation of sphericity assumptions, Condition: $F(1.446, 10.122)=12.105$, $p=0.003$; Dialect: $F(1, 7)=74.893$, $p<0.0001$; Condition × Dialect $F(1.446, 10.122)=1.372$, n.s.). Fig. 6 suggests that the significant Condition effect results from the onset condition standing out as being least retracted (most [i]-like), while the other four conditions appear all to be strongly darkened. In order to avoid an unnecessary multiplication of statistical testing, only a theoretically-motivated subset of all possible multiple comparisons were carried out in a planned post-hoc analysis. Two matched-samples *t*-tests were conducted, one comparing the a priori least ambiguous coda condition, coda_b, to the ambisyllabic condition, $t(8)=-1.228$, n.s., and one comparing this ambisyllabic condition to the onset condition, $t(8)=-3.150$, $p=0.014$. While the ambisyllabic condition may appear to show somewhat less retraction compared to the coda ones, this was not significant. Moreover, in three individual subjects, there was not even a trend for ambisyllabic /l/ to be intermediate between onset and coda. The results of the statistical analysis thus confirm that in terms of retraction away from palatal [i] contact, the ambisyllabic condition follows the coda, not the onset. Coda retraction is present strongly for the fake geminate sequence in *peel lemurs* (cf. Fig. 3b), and so we conclude that the coda identity of the first element of the geminate is preserved as the early part of an overlapping sequence which is rather longer in duration than a singleton /l/.

Scottish English has previously been described as having relatively "dark l" in both onset and coda position (Stuart-Smith et al., 2006), whereas SSBE is expected to show a greater allophonic differential, with a strongly dark /l/ in coda position only. This is broadly what we found, in articulatory terms. Overall, English speakers have a less retracted onset /l/ and a more retracted coda /l/ for all coda conditions. That is, the syllabification of /l/ in coda position is clearly marked by retraction, including the fake geminate condition. In terms of broad dialectal differences, the Scottish speakers, with the exception of S1 (the first author), have generally a fairly retracted /l/ in onset position compared to English ones, and for S2–S4, the difference between onset and coda /l/ is very small indeed.[11] S1 patterns similarly to the English speakers in that he shows a marked difference in retraction between onset and coda, and while we are well aware that this might somehow reflect knowledge of the purpose of the experiment, it may equally be sociophonetic variation.

English speakers E3 and E5 are of special interest. Recall that the tongue tip contact analysis revealed that they vocalise before /b/ but not before /h/. In terms of retraction, however, E3 retracts equally in both conditions, while E5 shows a small numeric difference with more retraction before /h/. Nonetheless, for both coda conditions /l/ is substantially more retracted compared to onset /l/. E4, who never vocalises, still shows a substantial difference in onset and coda /l/ retraction. Overall the results show that the presence or absence of tongue tip contact for /l/ in coda position is not determined by the degree of retraction in coda position. The independence of the lingual gestures implementing /l/ means that resyllabification of the segment /l/ is not a feasible model for what causes the alternation.

[11] Note however that we do not wish to imply that no systematic difference between onset and coda exists in articulation (or in acoustics) for these Scots, just that EPG does not reveal it. In Scobbie (2009), a speaker who was recorded with EPG and Ultrasound Tongue Imaging (S2) showed no difference in EPG darkness but examination of UTI data showed the tongue root is probably less advanced (darker) during [i], and probably more retracted during the [l], when /l/ is in a coda before /b/, by around 1 cm.

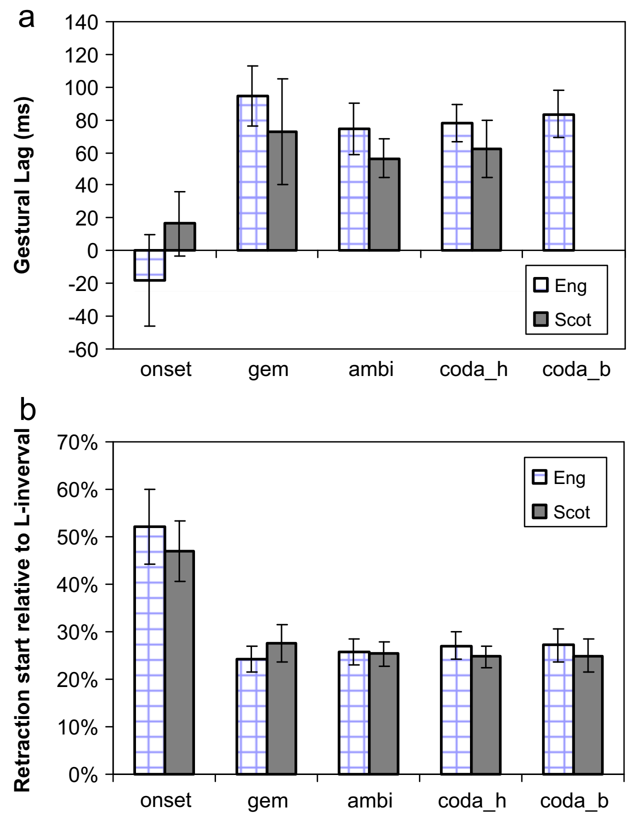

Fig. 7. Gestural lag. (a) Lag (positive values) of achievement of coronal contact behind start of dorsal retraction. (b) Relative lag of start of dorsal retraction after the burst of /p/ in *pee*/*peel*, expressed as a percentage of the duration of the speaker's L-interval. Whiskers indicate 1 SD in each direction.

3.3. Inter-gestural timing

In this section we investigate how the timing between the coronal and dorsal gesture is affected by condition. The relative temporal lag of the coronal gesture was calculated by subtracting the time point measured for the dorsal gesture from the time point measured for the alveolar gesture. A positive value indicates that the tongue tip landmark occurred later in time than the landmark of the dorsal gesture, whereas negative value indicates that the alveolar gesture reached its threshold value earlier than the dorsal gesture. Fig. 7a shows the results. For the Scottish speakers, timing could not be measured for the coda_b condition, because so many tokens were vocalised (see Fig. 4). For the by-subject data, the reader is referred to Appendix D.

The results again show a clear difference between the onset and coda conditions. As was the case for the degree of retraction results, the coda status of /l/ is unambiguously marked in the timing of the two gestures. As for the ambisyllabic condition, no intermediate timing patterns were found, contra expectations of the resyllabification model. In the onset, the measured lag between the two gestures is small, and the difference between the conditions increases by about 80–110 ms in the dark environments, similar to the findings of Gick et al. (2006).

Because this lag measure relates the beginning of retraction to the attainment of coronal contact (as discussed in Section 2.4), a qualitative visual inspection of the change in EPG patterns was undertaken to check how our measure relates to a more global characterisation of gestural alignment, paying attention to the estimated timing of maximal retraction and maximal coronal contact. For the English participants and S1 (the first author), inspection of the data reveals that low lag figures in the onset seem to be due to two factors: one is that the maxima of the gestures appear to be closely timed (in line with Sproat and Fujimura 1993), and the other is that the extent of retraction is far less (and in fact for some tokens fail to drop below the 80% threshold required for analysis of timing cf. Fig. 6 and Appendix D). A smaller extent of retraction might reasonably be expected to enable a later initiation of the movement, and therefore cause a smaller lag as measured. Note that the negative lag value means that the dorsal gesture in the onset is closer to the vowel, confirming at least partially the generalisation of Sproat and Fujimura (1993) that vocalic gestures are attracted to the syllable nucleus. For the other Scots (S2–4), for whom the extent of retraction in the onset is entirely comparable to the coda, the earlier retraction in the coda must be solely due to the dorsal gesture beginning earlier, showing unequivocally that timing matters (see also Fig. 7b, discussed below). A matched-samples *t*-test on the subject means was conducted to compare the onset condition to the ambisyllabic condition. The test reached significance at $p=0.002$ ($t(7)=-4.955$). Thus the timing for the ambisyllabic condition looks resolutely coda-like, contradicting Gick et al. (2006). The geminate condition is measured at the onset of the consonant constriction, so unsurprisingly reflects the coda /l/ member of the geminate, and patterns accordingly. As noted, some speakers have zero contact, but informal analysis indicates comparable results would be obtained from an analysis of timing based on the minimum placed at the midpoint of the period of least contact, which could be estimated in the case of zero contact.

A measurement of the timing of retraction timing relative to the start of the L-interval was undertaken because it can be made in vocalised and consonantal tokens alike (Fig. 7b). The results confirm that retraction begins early in the dark contexts both in absolute terms and normalised as a percentage of the L-interval.[12] The (English) alveolar gesture, on the other hand, appears stable in timing relative to the start of the L-interval.

3.4. Glottalisation in ambisyllabic tokens

One characteristic of the ambisyllabic condition is that tokens often display juncture glottalisation. Indeed, for half the speakers, (E1, E4, E5, S2, S4) every ambisyllabic token had glottalisation. The goal of the present analysis is therefore to determine whether high vocalisation rates and coda-like retraction in the ambisyllabic condition are due to the same factor causing glottalisation: is it an overt acoustic marker that the resyllabification of /l/ is blocked?

Glottalisation was identified auditorily and visually on the basis of the spectrogram and waveform in agreement between the two authors. Table 2 gives the percent vocalised (Voc) and consonantal (Cons) productions of /l/ in the pre-vocalic condition according to the presence or absence of glottalisation.

E1 & E4 have glottalisation plus consonantal /l/. (E1 nevertheless appears to have coda-like but not onset-like strength of contact in these ambisyllabic conditions, while E4 has similar contact strength everywhere, including the onset.) E2 & S5 have exclusively consonantal /l/ (bar one token) of which about three quarters feature glottalisation. E3 and E5 who vocalise before /b/ but not before /h/ have mostly consonantal tokens in the ambisyllabic condition. Interestingly, if it is present, juncture glottalisation patterns with the phoneme /h/ in permitting consonantal /l/ (92% of E5 and 38% of E3). Otherwise, consonantal /l/ is truly intervocalic (50% of E3). About 8% of E5's vocalised tokens show concomitant glottalisation, comparable to the small number of tokens which that subject vocalises before /h/. Finally, 12% of E3's tokens are vocalised despite the absence of glottalisation (i.e., despite being truly intervocalic).

Table 2
Proportions of vocalic (Voc) and consonantal (Cons) ambisyllabic tokens that are glottalised (ʔ) or not (–). Empty cells denote zero occurrences.

%	E1		E4		E2		E5		E3	
tokens	ʔ	–	ʔ	–	ʔ	–	ʔ	–	ʔ	–
Voc							8			12
Cons	100		100		75	25	92		38	50
	S2		S4		S1		S3		S5	
tokens	ʔ	–	ʔ	–	ʔ	–	ʔ	–	ʔ	–
Voc	100		83		22	17	42	4		4
Cons			17			61	46	8	71	25

Most revealing are the four Scottish speakers S1–S4, because they vary so much in the ambisyllabic condition, from 0% to 61% consonantal tokens (Fig. 4). S2 vocalises 100% before [ʔ], in line with their behaviour before /h/. S4 appears similar with 100% glottalisation in the ambisyllabic condition, but though 83% are vocalised, surprisingly 17% have alveolar contact. Like S2, S1 completely avoids consonantal /l/ with glottalisation, but otherwise they differ considerably: S1 has a consonantal /l/ in 61% of tokens (a truly intervocalic /l/) rather than vocalisation. When S1 does vocalise, glottalisation is present about half the time. Finally, S3 has a preference for glottalisation (88% of tokens), but there is a roughly equal number of vocalised and consonantal tokens of /l/.

Overall, no systematic pattern in EPG contact emerges across subjects or within the dialect groups (although impressionistically, glottalisation does appear to create a perception that /l/ is word-final, and dark). The predominant pattern across the two dialect groups seems to be a preference for glottalisation. At the same time, the English speakers' /l/ are rather more consonantal than vocalic in the ambisyllabic condition. To some extent it is vice versa for the Scottish speakers. However, glottalisation and /l/-vocalisation do not appear to be directly connected for either dialect group, and if they are, it is no more than a tendency.

4. General discussion and conclusions

Our results add to the literature on how English /l/ varies in its spatial and temporal articulatory properties as a function of its position within the word (which we have treated here as representative of onset and coda). Overall, speakers exhibit higher rates of vocalisation of coda /l/ at normal speech rates than might be expected from earlier studies of American English (e.g., Giles & Moll, 1975). There are also some broad dialectal differences within our speakers. Contact patterns in Southern Standard British English suggest that in the coda the tongue tip gesture is spatially reduced and the tongue dorsum is more retracted and initiated relatively earlier. In Scottish Standard English, alveolar contact may be very greatly reduced in the coda. In onset and coda alike, palatal contact patterns indicate dorsal retraction, and in the coda contexts, the retraction we observed is stronger and timed earlier. Furthermore, individual speakers vary greatly in *how* such differences between these allophones of /l/ are manifested, particularly in patterns of alveolar contact. Some

[12] Overall, the Scots have a slightly shorter L-interval in duration, but whether this is due to speech rate or phonological system differences in vowel duration, we are not sure. We should therefore note that the duration of the inter-gestural delay (Fig. 7a) taken as a percentage of a speaker's L-interval duration has the same lack of dialect difference revealed in Fig. 7b, and shows that retraction begins equally early, with the same increase in inter-gestural delay.

speakers show subtle differences in the degree of contact, others show a more categorical difference between onset and coda, the latter having no contact, and yet others do not appear to differentiate at all between the different conditions.

We have also confirmed experimentally the striking L-sandhi phenomenon previously noted in the Mocha-Timit corpus (Scobbie & Wrench, 2003; Wrench & Scobbie, 2003). Unsurprisingly, /l/ varies depending on the following word-initial segment, but the conditioning factors are both more subtle than simply pre-vocalic versus pre-consonantal context and the effects on /l/ appear to be at the level of the gesture rather than the segment. Thus these patterns of connected speech alternation in word-final English /l/ raise important theoretical questions about the factors that condition such alternation, its relevance for phonemics, and the role of syllable structure in connected speech, issues we will explore below.

At this point we should briefly take the chance to compare the results for two speakers with their behaviour in the corpus-based study reported by Scobbie and Wrench (2003). In that study, E4 was "SW" and E3 was "JW", and they both vocalised before labials in the majority of cases, but not before a vowel. In the current experiment, E4/SW did *not* vocalise before /b/ much, which is quite a different pattern. E3/JW on the other hand appears consistent with the earlier study, and does vocalise before /b/. (We did not examine pre-pausal coda here, but it is interesting to note that in that position, E3/JW did not vocalise, and while E4/SW did, to a large extent this was just in weak syllables.) The difference in materials and tasks may be responsible for the difference in E4/SW's results, but E3/JW does not change, which is another form of intra-speaker variation, across experiments.

Let us turn now to a more detailed examination of our results. First, consider the Scottish speakers. Gradient gestural reduction of the alveolar constriction is likely to be responsible for vocalisation in many cases, because partial reduction of the degree of contact in the different conditions patterns well with a speaker's tendency to lose alveolar contact completely (S2, S3, S4). A consistently larger distinction in degree of contact with more categorical variation in presence of contact is possible, for example for S1 (bearing in mind our concern that his data has to be treated with caution). And, dialectally, Scottish speakers may show less alveolar contact overall in the onset (about 11 contacts rather than 14 for the English speakers) and certainly produce more vocalised productions (except for S5, perhaps because he was also aware of the nature of the experiment). The three most reliable speakers (S2, S3, S4) exhibit generally a greater difference between onset and coda conditions in the behaviour of the alveolar contact in /l/ than they do in retraction degree or timing. S1 differentiates onset and coda in all three respects, and recall we have no timing data for S5. While the variability the Scottish speakers exhibit may be dialect specific, potentially enhanced by the fact that /l/-vocalisation is an ongoing sound change in many dialects (Johnson & Britain, 2007; Stuart-Smith et al., 2006), it could be spurious, and further research on naïve speakers is required. Scottish speakers have a tendency for a greater (but not relatively earlier) retraction of the tongue dorsum in the onset compared to English speakers, which tallies with previous discussion of dialect-specific onset darkness (Carter, 2002; Carter & Local, 2007).

Consider now the ambisyllabic (or word-final pre-vocalic) condition for which we found interesting inter-speaker differences. While the tongue tip contact pattern for English speakers is mostly similar to onset /l/, for E1 and more dramatically for the Scottish speakers S2, S3, S4 the tokens are more similar to those found in the coda conditions. S5 is onset-like so far as we can tell, and S1 is onset-like in terms of degree of contact, coda-like in retraction, and intermediate in terms of number of tokens with contact. Averaging across speakers would therefore give the appearance of intermediacy in the ambisyllabic condition. However, when we turn to its retraction pattern, for all speakers ambisyllabic /l/ is revealed to be coda-like: even when pre-vocalic, these word-final /l/ tokens show the same retraction pattern as they do when they are pre-consonantal, that is, just like unambiguous codas.[13] The two gestures of /l/ behave somewhat independently. The tongue tip gesture may or may not be onset-like while the tongue dorsum invariably displays the spatial characteristics of a coda consonant.

What is the actual factor that conditions variation in the ambisyllabic condition: prosodic structure (the /l/ associates to the onset) or linear order (the /l/ is pre-vocalic)? A priori, the independent patterning of alveolar and palatal contact argues against ambisyllabicity, but perhaps we could develop a new conception of ambisyllabic behaviour drawing on the partial independence of gestures (see below). Under such an interpretation, ambisyllabicity would not be manifest as intermediate movement amplitude or timing (as for instance assumed by, among others, Gick, 2003), but in a disjoint (non-segmental) syllable affiliation of the two gestures of /l/. Specifically, it could be that the tongue dorsum gesture remains unambiguously associated with the coda position, while the tongue tip gesture becomes solely or additionally affiliated with the following onset. However, no support for this hypothesis can be drawn from the timing patterns of the two gestures: the lag from the dorsal retraction to the tongue tip gesture does not increase in ambisyllabic position compared to the pre-consonantal conditions as might be expected if the alveolar gesture gains an onset affiliation. More strongly, the patterning of the two gestures in the pre-consonantal conditions speaks against a non-segmental ambisyllabicity analysis, because our results do not support a straightforward separation into pre-consonantal vs. pre-vocalic contexts.

Let us explore then an alternative option, that L-sandhi is due to the co-ordination of gestures post-lexically in a gestural score which preserves word-internal syllabification. Most speakers do not exhibit alternation in word-final /l/, but if they do, the pattern seems to be that vocalisation of word-final /l/ is less likely if the following word is vowel-initial. Most speakers show the same pattern before /b/ and /h/ in that they vocalise before both or before neither. However, two speakers' patterns suggest that /b/ and /h/ can be differentiated linguistically in how they condition the behaviour of a preceding word-final /l/. For these two English subjects (whose /l/ are strongly consonantal and thus onset-like in the ambisyllabic condition) the /b/ condition appears to be a coda context for /l/ both in terms of the tongue tip contact pattern and degree of retraction (cf. Scobbie and Wrench 2003 for confirmation that word-internal /lb/, not examined here, shows strong vocalisation). The /h/ condition, however, is ambivalent in the tongue tip behaviour it conditions: while the retraction values indicate a coda /l/, the tongue tip contact pattern is typical for onset /l/ for E4 and, to a lesser extent, E3. Timing results for individual speakers (Appendix D) show there is no difference between ambisyllabic and coda-/h/ on the one hand or coda-/b/ on the other (though in the latter case, data is scanty due to high vocalisation rates).

Recall that Sproat and Fujimura (1993) also included an /h/ condition in their materials (e.g. "Mr Neal Hikkóvky's from Maddison"). They found for at least the one speaker for whom

[13] Methodologically, it would have been useful to add conditions with word-final /lC/ where C is labial. The /lC/ would then be varied so it was either pre-consonantal or pre-vocalic. However, no such words with the /i/ vowel exist in English. We would predict, from Scobbie and Wrench (2003), that the /l/ would be very likely vocalised in both cases. Moreover, we know already from that previous study that strong and weak syllables can behave differently, so, as a reviewer points out, it may well be that the generalisation about retraction patterns only holds for strong syllables.

results were presented ("CS") that the tip delay measure of interarticulatory timing (which captured neatly the increasing darkness of ambisyllabic /l/ across increasingly strong boundaries) was hugely variable, spanning almost the entire range, from the earliest case, where the tip was in advance, to cases where the tip was very late.[14]

Both /h/ and /b/ are onset consonants, and neither is specified for lingual gestures. If syllable structure and underspecified internal structure were to be the only factors driving the external sandhi alternation between consonantal and vocalic /l/, then /h/ and /b/ would always pattern together, given the phonotactic illegality of */lh/ & */lb/ as onsets. It could be argued that /h/ is totally placeless rather than just non-lingual, and an attempt made to derive the difference with /b/ thereby, but this would also be to deny that the alternation is driven exclusively by syllabicity.

Finally, consider what happens to word-final /l/ when the following word begins with a phonemic vowel (the ambisyllabic condition). We noted that the vowel may be accompanied by phonetic glottalisation, usually [ʔ]. The speakers (all SSBE) who exhibit consonantal /l/ before a following /b/ and /h/ (E1, E2, E4) or just /h/ (additionally E5) are also consonantal in the ambisyllabic condition. Whether this is coincidence or not, for these speakers, this juncture is overwhelmingly glottalised. (E3 is intermediate in the /h/ condition in terms of degree of contact, and tends not to glottalise in the ambisyllabic condition.) The speakers who vocalise in both coda conditions (all Scottish) *also* prefer glottalised ambisyllabic productions, but this time /l/ is more often than not vocalised. However, S3's pattern shows that glottalisation is not an automatic bar on consonantal /l/. So [ʔ], like phonemic /h/, does not necessarily condition vocalisation. Word-initial [ʔ] is not an allophone of any phonemic consonant of English (though in other positions it is an allophone of /t/), so perhaps it is not too surprising that it does not act like an onset, but the behaviour of /h/ for E3 and E5 remains harder to explain. More broadly, the behaviour of /h/ and [ʔ] vs. /b/ leads us to expect that English R-sandhi may likewise not be blocked by these consonants, a prediction which needs to be investigated in future research.

To summarise, the behaviour of /l/ is difficult to account for within a segmental and syllabification based account in which the onset-like or coda-like nature of word-final /l/ is said to be conditioned exclusively by its phonological association to either its lexical coda or to the onset of a new syllable whose nucleus is found in the following word. First of all, we observe in two speakers (E3 and E5) differences in /l/ in conditions in which no resyllabification is expected, that is, before two different non-lingual word-initial consonants, /h/ and /b/. Secondly, and turning to the ambisyllabic condition again, in a segmental approach to speech production it is not predicted that one of the gestures of /l/ is resyllabified (the tongue tip gesture), while the other is not. Yet, this is exactly what seems to be required, given the behaviour of speakers E3, E5 and S1. These are the speakers whose alveolar data in the ambisyllabic condition is onset-like in terms of degree of contact (as opposed to the coda /b/ condition), but whose retraction remains coda-like. Thirdly, glottalisation cannot simply correspond to a filled or unavailable onset, which would block resyllabification, because its effects are inconsistent.

Rather, our view is that these data lend support to a gestural theory of connected speech sandhi and speech production generally, in which autonomous gestures, metaphorically often described as the atoms of speech production, cohere into larger molecular structures on the basis of inter-gestural coupling (Goldstein, Byrd, & Saltzman, 2006). On this view, there is no privileged status for the segment, which is an emergent, more abstract alignment of gestures each on its own temporal tier, with the result that a segment appears to be present (or absent) as a unit (Browman & Goldstein, 1990). Our results may also support Generative formalisms which permit features attached to non-terminals in a feature tree (e.g., Coleman, 1994). Interestingly, the two traditions come together somewhat in recent work, also on liquids (Carter, 2002, 2003, p. 251), where the dorsal content of /l/ is specified at rhyme level while the apical specification is in the coda. Such an approach would presumably predict feature-based rather than segmental resyllabification.

It is Articulatory Phonology, however, which might provide a general explanation for the different behaviour of the gestures, linking back in a way to Sproat and Fujimura (1993). Basically, in coda position, inter-gestural coupling has been hypothesised to be weaker compared to onset position (Byrd, 1995; Krakow, 1999; Marin & Pouplier, 2008, in press; Nam, 2006). Our data lend further empirical support to this approach. The gestural dissociation of word-final /l/ shows that the more vocalic articulation of retraction is relatively stable, while the more consonantal alveolar gesture varies greatly in how it is timed, and in its strength.

Overall, it thus seems that in connected speech we observe word-to-word interactions conditioned by relationships somewhat like, but not identical to, syllabification. Our view is that strong categorical differences between onset/coda allophones are able to arise from a previously less divergent pair of allophones because of the categorical structural differences between onset and coda *within* words. If lexical representations are not symbolic segments, but articulatory scores comprising gestures which cohere into greater molecular structures through coupling relations, syllable affiliation itself becomes a gradient phenomenon. A proposal of how gradient and categorical surface phenomena may arise from an underlyingly continuous dynamical system is exemplified in Gafos (2006) as well as Gafos and Benus (2006).

Under the influence of general coarticulatory tendencies within words there may thus be a potential for gradient differences to diverge further across them. If the lexicon, as exemplar theory suggests (Pierrehumbert, 2000), contains often-encountered and semantically-coherent units such as phonological words and common collocations, then the lexical gestural co-ordination patterns at word edges will vary in connected speech under the influence of general coarticulatory tendencies, but will approximate to well-rehearsed word-internal attractors (or high frequency post-lexical ones). A gesturally-complex word-final consonant with its relatively weaker "internal" coupling is going to be more influenced by its connected speech context (and display a greater range of divergent variants dependent on coarticulatory pressures) than the same abstract unit in word-initial position, where its gestures will be more strongly coupled. Moreover, the local co-ordination of word-final codas makes them less tightly bound at an articulatory level to the preceding vowel, and more able to be bound to a following one should it be present (Browman & Goldstein, 2000). Through the asymmetric strength in binding, a word-final consonant is thus predicted to be more likely to become onset-like when pre-vocalic, if the words are able to be tightly co-ordinated at a phonetic level by being prosodically close, without any requirement for changing phonological syllable structure itself across word boundaries.

This model is also compatible with the findings from Sproat and Fujimura (1993), who found decreasing tip-dorsal cohesion in high front vowel ambisyllabic contexts spanning prosodic boundaries of gradually increasing strength. The boundary strength in our materials is intermediate between their "V" and "P" contexts (VP boundary and VP-internal boundary), which they

[14] Thanks to Ricardo Bermúdez-Otero for bringing this to our attention. In the absence of any textual discussion by Sproat and Fujimura, it is hard to know the reasons for or generality of this pattern. We certainly found no such extreme variation: our timing measures in the relevant contexts have similar standard deviations to each other (Appendix D) when they could be measured (for the SSBE speakers).

found to be relatively dark in terms of acoustic quality, acoustic rime duration, and most relevant here, articulatory timing. They found about 50–100 ms of tip delay, comparable to ours.

Sproat and Fujimura's results strongly challenged the then-popular view that /l/ allophony involved only light and dark allophones, based on their findings that ambisyllabic darkness is gradient given different prosodic boundaries. Our findings about how alveolar contact varies in different segmental contexts similarly indicate that the traditional view is inappropriate, but show a different, more complex, and speaker-specific variation which crosscuts the prosodically-conditioned gradience of darkness. While for some speakers the variation appears gradient, the alveolar gesture for /l/ can been seen to be more categorically-distributed for some speakers, e.g. S1 here and in Wrench and Scobbie (2003) and AS in Scobbie and Wrench (2003). In other words, some aspects of L-sandhi appear more categorical, others more gradient. Variation of word-final consonants surely ranges from subtle adoption of onset-like characteristics in a pre-vocalic context, right through to strong and categorical behaviour indicative of a more abstract aspect of representation (e.g., Kochetov & Pouplier, 2008; Ladd & Scobbie, 2003): here we seem to see that a range of behaviour is possible even within what might be seen as a single phenomenon from a strongly segmental viewpoint, challenging any simple modular view of the phonetics/phonology interface, including that of Sproat and Fujimura (1993, p. 306) in which /l/ allophony was seen as not being represented at any level of phonological representation. One of the major difficulties with such a strict modular view is that it is unable to address the question of how abstract categories can ever gradually arise (Scobbie, 2007).

Our gestural-episodic viewpoint claims at its heart that the alternants of word-final /l/ are not identical copies of word-internal allophones of /l/, as an algebraic Generative Phonology model predicts: the word-final phone in various connected speech contexts merely *resembles* to some extent phones from other positions in the word. Alternation patterns and the phonetic similarity of allophones and alternants are basic criteria appealed to in phonological analysis, as part of the justification for abstract categories (aka phonemes), which it must be remembered are analytic constructs, and not givens (Bybee, 2001; Scobbie, 2007). Such phonological identity covers what may be phonetically very different allophones, which exist in complementary distribution. In the case of English /l/, in dialects with large allophonic differences such as coda vocalisation, the alternation of word-final /l/ in L-sandhi is just one such clear bit of evidence motivating the existence of such an abstract /l/, even if the word-final allophone of /l/ retains some of its coda qualities and is not identical to word-initial /l/, but instead is "intermediate" in some way.

In the more traditional phonological view, resyllabification is categorical and structure-preserving in terms of the onsets created. In the case of /l/ before /h/ and /l/ before /b/, such a model struggles with the systems of E3 and E5, because it would either have to create impossible onsets such as /lh/, or claim that alveolar contact is due to resyllabification before vowels, but due to some other process before /h/. The gestural-episodic model however appears to deal with these speakers more easily. The onset /h/ differs from labial consonants in how it conditions the allophone of word-final /l/ as a consequence of continuous gestural co-ordination processes arising ultimately from the differences in how pre-vocalic and post-vocalic consonants are co-ordinated with adjacent vowels and consonants, not due to phonological resyllabification. We thus expect sandhi phenomena involving liaison to vary cross-linguistically depending on how connected speech is implemented and planned in terms of the demarcative phonetics of words and phrases.

Such co-ordination is expected to be stored as part of the lexical entry of isolated words. Though word-internal /lb/ sequences are rare as types in English (but *bulb*, *elbow*, *album* are relatively commonplace), sequences of /l/ plus a labial consonant are well-attested. In connected speech, if contexts arise which closely resemble frequent word-internal structures, those highly rehearsed word-internal routines will act as attractors, giving rise to contextual variation in the way the word-final consonant is pronounced. Thus post-lexical /l#b/ sequences will tend to resemble word-internal /l/ +labial sequences. Post-lexical /l#h/ on the other hand is a novel sequence, given the virtual absence of English words with word-internal /lh/ sequences other than those occuring across the boundary of noun-noun compounds.[15] It is more likely to attract to word-internal /l/+vowel sequences, which it most closely resembles. Moreoever, /h/ itself varies a great deal. As shown by Zharkova (2007), for example, word-initial /h/ is largely a laryngeal gesture overlaid on the vowel, and the lingual articulation during /h/ undergoes an extreme degree of progressive coarticulation (cf. also Catford, 1977). The issue here is how the more loosely bound alveolar gesture of a preceding word-final /l/ is co-ordinated with the /h/. We think that in the (near) absence of word-internal /lh/ sequences the presence of the laryngeal devoicing gesture of /h/ is unlikely to affect the cross-word co-ordination, making /l/ therefore more likely to behave as if it were pre-vocalic.

Post-lexical assimilation has been understood in terms of gradient overlap and gestural reduction for some time (Browman & Goldstein, 1990), but there is generally still assumed to be a role for syllable-based alternation, which our results challenge, for this case specifically and perhaps more generally. While we do not rule out categorical post-lexical phonology (because after all phonology is at heart an abstraction) we echo Browman and Goldstein's earlier work in challenging the assumed categorical status of some post-lexical phenomena. We do not think formal resyllabification is a fundamental force behind the particular connected speech process discussed here, and do not think that the many cases of "ambisyllabicity" in the literature need to involve a change in syllable structure. We thus differ from Jensen (2000), who argues against ambisyllabicity, but on the basis of traditional segmental transcription data (the accuracy of which has to be doubted). Rather, we think that the bulk of instrumental phonetic evidence supports our view precisely because word-final consonants vary, and often appear to be intermediate between onset-like and coda-like forms. Similar conclusions can be reached from the consideration of subtle changes in the production of reiterated CV and VC sequences in fast speech (de Jong, 2001; Kelso, Saltzman, & Tuller, 1986) which are heard changing categorically from one to the other.

Our position finds support from the consideration of word-final /l/ in a very different coda context. Scobbie and Wrench (2003) and Wrench and Scobbie (2003) using the Mocha-Timit EPG-EMA corpus looked at pre-pausal utterance-final position (ostensibly a coda) and found half their eight speakers (including E4/SW and E3/JW) had far lower rates of vocalisation than they did before a labial consonant either within a word or across word boundaries (phrase-medially, of course). Those results confirm that knowing that an /l/ is "in the coda" is on its own not enough to predict whether it is vocalised or not. Nor would it be relevant if vocalisation became more likely as the boundary strength following the /l/ increased. Pre-pausally, where there is no following labial consonant, the alveolar gesture of word-final /l/ is more likely to survive, somewhat weakened and delayed. However, it is frequently absent (or massively weakened) in word-internal pre-labial codas due, perhaps, to the routinised masking of the delayed weak lingual contact by the labial. In

[15] Examples are *Alhambra*, used locally as a theatre name in England and Scotland, *bilharzia*, and *girlhood*. *Philharmonic* lacks an /h/ in British English.

word-final codas in a pre-labial context, the alveolar contact patterns of the /l/ are more likely to resemble those seen by Scobbie and Wrench (2003) for word-internal codas, namely vocalisation. Thus mechanisms of gestural overlap and co-ordination seem to offer a greater potential for understanding why some contexts rather than others condition partial or absolute loss of alveolar contact in /l/ than even lexical syllabification, given that different types of coda behave differently. A further small difference, which also argues for a gestural weakening approach, is that in the pre-pausal context, lexical stress is a factor: two speakers (SW/E4 and SS) vocalise /l/ in unstressed syllables, but not in primary stressed syllables. In other contexts, the stress of the word-final syllable does not appear to be relevant (though those Mocha-Timit studies with heterogeneous materials were not able to examine the extent of contact, so subtle weakenings which might be expected, were not measurable).

What then of the abstract phonological category /l/? In time it may come to pass that the pronunciation of its onset and coda phones will become so different, or that the alternation will be so diminished, that there is no longer a reasonable motivation for speakers to postulate in their systems that the sounds at the beginning and end of *leaf* and *feel* (respectively) belong to the same phonological category at all, just as has happened to /r/ in non-rhotic varieties of English in words like *reef* and *fear*. On the view of Scobbie, Stuart-Smith, and Lawson (2008), this process itself of (re)phonologisation is gradient and non-deterministic, and not limited to trans-generational misacquisition (e.g., Ohala, 1981) and can be gradient within the individual as well as at a population level. Insights into synchronic and diachronic patterns alike are, we think, more likely to arise from consideration of inter-gestural timing and co-ordination, frequency effects and variation than from uniform formal phonological models relying on phonotactics to control the resyllabification of segment-sized units.

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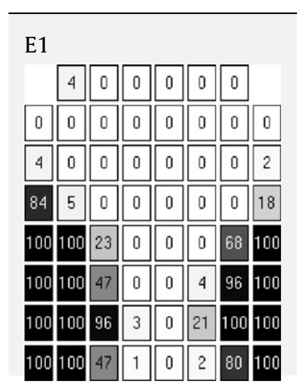
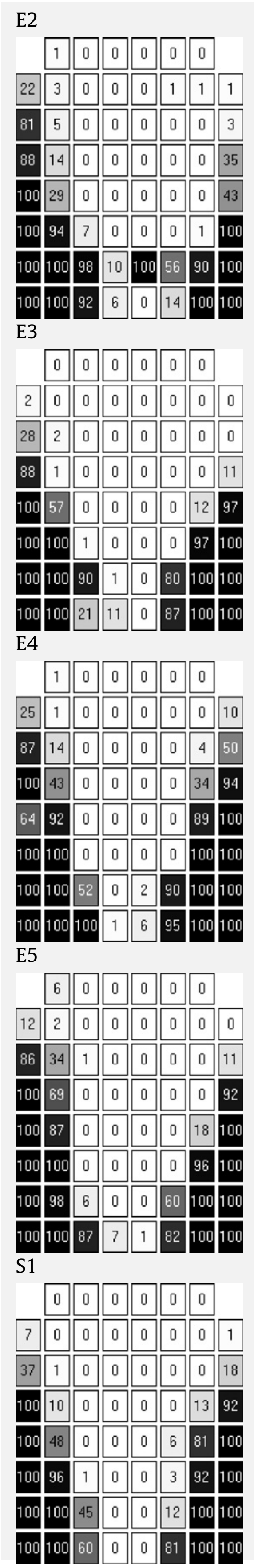
Appendix A. Materials

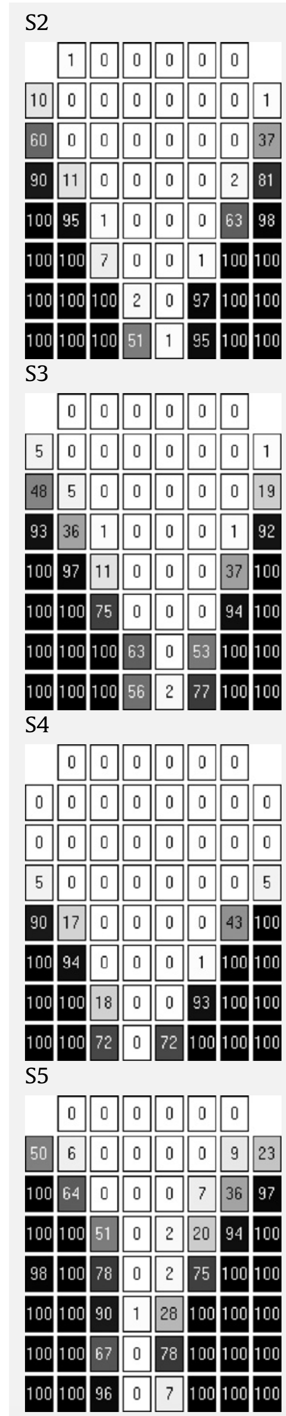
Can we pee leeward in gale force winds?
Can we pee leeward in a gentle breeze?
Can we pee Lima's and Rio's worst beers away?
Can we pee Lima's and Rio's best beers away?
Can we peel evening wear off the male model?
Can we peel Evening Oil patches from your elbow?
Can we peel Eve an apple and a banana?
Can we peel Eve any pear or apple?
Can we peel Eva (/ivə/) some fruit from the shops?
Can we peel Eva some fruit from the basket?
Can we peel lemurs for the taxidermist tomorrow?
Can we peel lemurs in the forests of Madagascar?
Can we peel BBC (/bibisi/) advertising from the shop window?
Can we peel BBC stickers from the car window?
Can we peel beavers in Canada's northern wastes?
Can we peel beavers on America's southern border?
Can we peel heaps of asparagus stalks?
Can we peel heaps of vegetable leaves?
Can we peel haematite (/himətait/) stickers off the geology worksheet?
Can we peel haematite posters off the wall?
Can we peel heaving and retching sailors off the deck?
Can we peel heaving and retching sailors off the rail?

Appendix B. Reference i-zone patterns for each subject

Mean [i] contact patterns (n=88). For speaker E2, the fifth electrode from the left in the last row but one was not taken into consideration, since it consistently showed contact during the entire experiment. Palate design for S5 was a prototype, and different from that worn by the other participants, so was not included in extent of contact analyses.







Appendix C. Degree of contact

For each speaker, three types of information are given. First, there is the mean and standard deviation in % of the maximum contact in the L-zone (cons-L degree of contact analysis). These values were normalised relative to onset on a speaker-specific basis for Fig. 5. Second, counts of tokens collected and available for analysis are given along with counts of tokens with any contact at all in the L-zone (i.e. at least one cell in one frame, where tokens with zero contact were excluded) providing the data for Fig. 3. Finally, the mean and standard deviation (as %) of the minimum i-zone contact (i-zone degree of contact analysis) are given. These are the basis of Fig. 6. All tokens were analysed for i-zone (see Table C1).

Table C1

		Max cons-L		L-zone contact		Min i-max	
E1	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	90	8	16	16	57	7
	Amb	38	15	24	24	6	4
	Gem	85	9	8	8	1	2
	coda_h	43	14	19	24	3	3
	coda_b	32	16	11	16	5	4
E2	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	72	6	16	16	64	9
	Amb	59	8	24	24	45	13
	Gem	76	6	8	8	31	12
	coda_h	64	4	24	24	30	8
	coda_b	54	9	16	16	30	4
E3	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	90	11	16	16	72	11
	Amb	51	26	22	16	41	17
	Gem	85	13	8	8	13	14
	coda_h	47	20	18	24	30	14
	coda_b	6	0	3	16	29	7
E4	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	66	11	16	16	72	6
	Amb	62	14	24	8	7	4
	Gem	76	13	8	24	11	3
	coda_h	57	10	24	24	8	5
	coda_b	56	7	16	16	11	7
E5	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	77	5	16	16	73	6
	Amb	68	20	24	24	25	6
	Gem	77	4	8	8	38	10
	coda_h	64	24	24	24	21	11
	coda_b	9	5	15	16	33	4
		Max cons-L		L-zone contact		Min i-max	
S1	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	42	5	12	12	81	6
	Amb	45	10	11	18	26	13
	Gem	64	3	6	6	12	4
	coda_h	6	0	2	18	15	6
	coda_b	6	n.a.	1	12	7	4
S2	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	74	12	15	15	30	12
	Amb	6	0	3	22	40	10
	Gem	90	5	8	8	12	4
	coda_h	28	n.a.	1	22	43	9
	coda_b	0	0	0	13	49	6
S3	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	85	19	16	16	43	16
	Amb	15	13	16	24	39	8
	Gem	92	3	8	8	16	2
	coda_h	9	3	3	24	30	9
	coda_b	6	0	2	16	27	8
S4	Condition	Mean (%)	SD (%)	Count	Total	Mean	SD
	Ons	42	8	16	16	47	6
	Amb	14	11	4	24	40	6
	Gem	58	6	8	8	34	2
	coda_h	6	n.a.	1	24	35	8
	coda_b	0	0	1	16	30	4
S5	Condition	Mean	SD	Count	Total	Mean	SD
	Ons			16	16		
	Amb			16	24		
	Gem			8	8		
	coda_h			23	24		
	coda_b			15	16		

Appendix D. Timing values

Tables give the mean lag (in ms) between the achievement of alveolar constriction and beginning of retraction. Negative values indicate the alveolar gesture is in advance of retraction (see Table D1).

Table D1

E1	Condition	Mean	SD	Tokens
	ons	−1	12	15
	amb	73	12	24
	gem	90	12	8
	coda_h	78	11	19
	coda_b	89	7	12
E2	Condition	Mean	SD	Tokens
	ons	−18	20	13
	amb	55	19	20
	gem	82	21	8
	coda_h	63	13	24
	coda_b	67	17	16
E3	Condition	Mean	SD	Tokens
	ons	4	16	8
	amb	66	12	22
	gem	82	15	8
	coda_h	73	8	18
	coda_b	n.a.		0
E4	Condition	Mean	SD	Tokens
	ons	−9	9	14
	amb	96	12	24
	gem	126	30	5
	coda_h	93	14	24
	coda_b	95	19	14
E5	Condition	Mean	SD	Tokens
	ons	−66	24	12
	amb	83	15	22
	gem	94	17	8
	coda_h	82	16	21
	coda_b	n.a.		1
S1	Condition	Mean	SD	Tokens
	ons	−9	10	3
	amb	54	13	11
	gem	109	16	6
	coda_h	n.a.		0
	coda_b	n.a.		0
S2	Condition	Mean	SD	Tokens
	ons	14	12	15
	amb	na	na	0
	gem	75	28	8
	coda_h	n.a.		1
	coda_b	n.a.		0
S3	Condition	Mean	SD	Tokens
	ons	37	12	16
	amb	46	20	11
	gem	30	14	8
	coda_h	44	15	3
	coda_b	n.a.		0
S4	Condition	Mean	SD	Tokens
	ons	25	17	16
	amb	69	14	4
	gem	77	16	8
	coda_h	n.a.		1
	coda_b	n.a.		0

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