The effects of syllable and sentential position on the timing of lingual gestures in /l/ and /r/

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ABSTRACT

This paper is an ultrasound-based articulatory study of the impact of syllable-position and utterance position on gesture timing in liquid consonants in American, Irish and Scottish English. Mixed effects modelling was used to analyse variation in the relative timing of the anterior and posterior lingual gestures for /l/ and /r/ in syllable-onset and coda position and in utterance-initial, medial and final position. Results showed that the component lingual gestures for /l/ and /r/ are coordinated differently in onsets and codas, across the three varieties studied; the anterior lingual gesture tends to precede the posterior gesture in syllable-onset liquids, while this gesture order is reversed for syllable-coda liquids. For /l/, but not /r/, being in utterance-initial and final position results in a significantly increased temporal distance between the two lingual gestures. For coda /r/, prerhotic vowels were found to have a significant impact on the relative timing of lingual gestures.

Keywords: Articulatory Phonetics, Ultrasound Tongue Imagine, syllable structure.

1. INTRODUCTION

Previous articulatory research has shown that, in consonantal segments that are produced with multiple gestures, gestural organisation and variation in temporal separation of gestures can be affected by a segment's position in both the syllable and that segment's position relative to syntactic or prosodic boundaries [2], [8]. This variation in gesture order and separation affects the phonetic quality of segments, contributing to syllable-based allophony [8] and is likely to have a role in diachronic change, e.g. loss/vocalisation of coda consonants [5]. Studies to date have often focussed on single varieties/languages (but see [3]) or involve an analysis of one or two speakers per variety/language [3]. The present study considers the impact of syllable and utterance position on variation in the organisation and timing of the anterior and posterior lingual gestures in the liquid consonants (/l/ and /r/), articulatorily-complex speech sounds that often show extreme patterns of allophony, for multiple speakers of American, Scottish and Irish English. Our research questions are:

(1) What effects do syllable position and utterance position have on the timing of lingual gestures in liquid consonants?
(2) What is the impact of tautosyllabic vowel quality on the timing of lingual gestures in liquid consonants?
(3) Is liquid gesture timing variation similar across different accent varieties of English?

2. METHOD

6 Scottish speakers, 10 American speakers and 4 Irish speakers (from the Republic of Ireland) were recorded with ultrasound tongue imaging (UTI – Sonix RP machine, 111fps, 150° fan angle) reading aloud 80 sentences (c11 syllables long), e.g. *Rays of light are both wave and particle*. Each sentence contained at least one stressed monosyllabic key word, e.g. *rays*, with a liquid consonant in onset or coda position and each key word was positioned at the beginning, middle, or end of the utterance. There were circa 8 instances of /l/ or /r/ in each syllabic-utterance position per speaker. Utterance-medial liquids were always phrase medial, i.e. not positioned adjacent to a phrase boundary. All tokens of /r/ were approximants. Key words contained one of three high-front vowels /e/, /ɛ/, /ɪ/, to maximise ability to identify gestures belonging to the liquid consonants, but also to investigate the impact of vowel type (e.g. checked versus nonchecked) on lingual gesture timing. Lingual consonants were avoided in the two preceding and two following segments adjacent to the key segment in order to mitigate against consonantal coarticulatory effects. We aimed, as far as possible, to have high vowels in syllables adjacent to the key consonantal segments in order to be able to more easily identify tongue gestures associated with the liquid consonant.

2.1. Articulatory measures

Intergestural durational measures were taken from ultrasound video using Articulate Assistant Advanced (AAA) v2.16.12, (Wrench 2012). The maxima of the anterior and posterior lingual gestures

of /r/ and /l/ were annotated by the first author. For /r/, the anterior gesture could be an alveolar/retroflex or dorsal/tongue-front gesture (the latter for bunched variants of /r/). The posterior gesture for /r/ was a tongue-root retraction gesture. For /l/, the anterior gesture was a tongue-tip-raising gesture and the posterior, either raising of the tongue dorsum towards the velum, or retraction of the dorsum towards the pharynx. At the temporal point where the tongue surface first reached its highest, or backest, point an annotation was added. If either the anterior or posterior gestural maximum could not be identified, the token was excluded. The first author also manually annotated the onset and offset of the vowel + liquid consonant (Vl/r) section of the syllable using Praat v6.0.23 [1] using acoustic information (spectrogram, and intensity and pitch trackers). This measure of the duration of the Vl/r section of the key word was used to normalise the raw intergestural measures, but variation in the Vl/r duration across utterance positions was also analysed to identify whether there was syllable lengthening adjacent to major prosodic boundaries.

Raw temporal measures in the study were (1) the duration between the anterior and posterior gesture maxima (intergestural duration), and (2) Vl/r duration. In order to take account of different speech rates, measure (1) was normalised by expressing it as a proportion of measure (2). Raw and normalised durational measures were highly correlated, r_P=0.96.

2.2. Statistical analysis

Mixed effects modelling, carried out in R v.3.3.2, was used to determine the impact of position on normalised intergestural duration, but also to determine whether tautosyllabic vowel and speaker accent affected this measure. The effects of syllable and sentence position were studied across three accents of English in order to assess how fundamental these effects are in the language.

For the normalised intergestural duration measure in the /l/ data subset (N=587), we constructed a model including fixed factors: (1) *syllable position*, with levels (i) onset and (ii) coda; (2) *utterance position*, with levels (i) initial, (ii) medial, (iii) final; (3) *speaker accent*, with levels (i) Irish, (ii) American, (iii) Scottish and (4) *tautosyllabic vowel* with levels (i) /e/, (ii) /ɪ/, (iii) /ɛ/. We tested for two-way and three-way interactions between *utterance position*, *syllable position* and *region.*

For the /r/ data subset (N=587), we constructed a model including fixed factors: (1) *syllable position*, (2) *utterance position* (3) *speaker accent* and (4) *checked status of the tautosyllabic vowel*[1], with levels (i) checked (ii) unchecked. The checked status of the tautosyllabic vowel has been shown to affect lingual gesture timing in /r/ see [6] and [5]. We tested for two-way and three-way interactions between *utterance position*, *syllable position*, *region*, and *checked.*

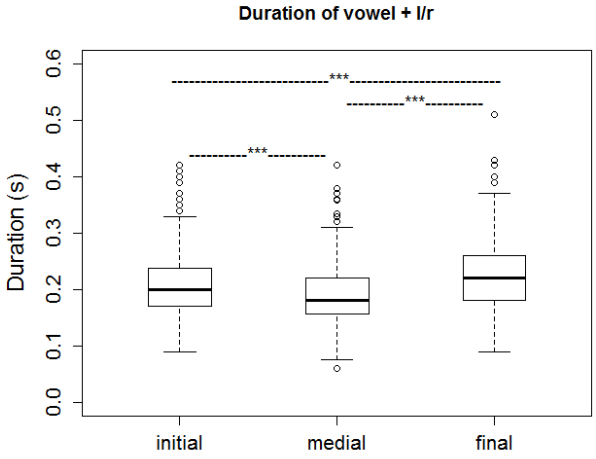
Random factors included in all models were: *speaker* and *word*. The step( ) function in the LmerTest package [4] was used to find models that best fit the data.

3. RESULTS

3.1 V+liquid durational variation

Firstly, we report on positionally-conditioned variation in the durational measure of Vl/r, which was used to normalise articulatory measures, see Fig. 1.

Figure 1: Variation in durational measures for Vl/r according to sentential position.



An ANOVA showed significant differences between Vl/r durations in all three utterance positions F=45.59 p<0.001. Mean Vl/r durations were: medial 191ms, initial 205ms and final 226ms. This result indicates that syllable-lengthening occurs at utterance edges, but particularly in utterance-final position. This result is of interest as it has been hypothesised that syllable lengthening at prosodic boundaries allows articulatory gestures to move further apart [8], which could lead to greater degrees of liquid consonant vocalisation in this position.

3.1. Intergestural duration, /l/

The final model for normalised intergestural duration for the /l/ dataset included a significant interaction between *syllable position*utterance position* F=13.73 p<0.001. There was also a significant effect of *accent* F=4.05 p<0.05, with Scottish speakers having significantly greater intergestural durations for /l/ than American speakers. Fig. 2 below shows

the interaction between *syllable position* and *utterance position*. The dotted line in Fig 2 represents the point where the maxima of anterior and posterior gestures are completely synchronous. Data points below the line indicate that the anterior lingual gesture occurred before the posterior gesture, while data points above the line indicate that the anterior gesture occurred after the posterior gesture.

Figure 2: Interaction plot for factors *syllable position* and *utterance position* for /l/ - dependent variable, normalised intergestural duration.

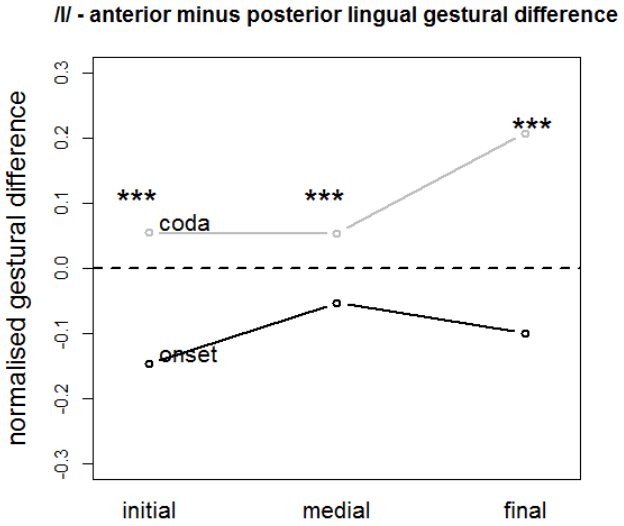


Fig. 2 shows that, for /l/ there is a clear pattern of syllable-based gestural organisation that is augmented by utterance position. For /l/ in onset position, the anterior gesture tends to occur first, while for coda /l/, the posterior gesture tends occur first. This variation is significant to the $p<0.001$ level in all sentential positions; however, Fig. 2 also shows extremes of gestural separation when /l/ is adjacent to utterance boundaries: the greatest degrees of gestural separation occur for coda-/l/ in utterance-final position and onset-/l/ in utterance-initial position.

3.2. Intergestural duration, /r/

The best-fit model for the normalised intergestural duration of /r/ contained two significant interactions between *syllable position*checked status of the tautosyllabic vowel* $F=20.10$ $p<0.001$, and *syllable position*speaker accent* $F=5.17$, $p<0.01$. The random factor *word* was significant: $\chi=6.21$, $p<0.05$. Fig. 3 illustrates the interaction between *syllable position* and *checked*.

Figure 3: Interaction plot for factors *syllable position* and *checked* for normalised intergestural duration in /r/.

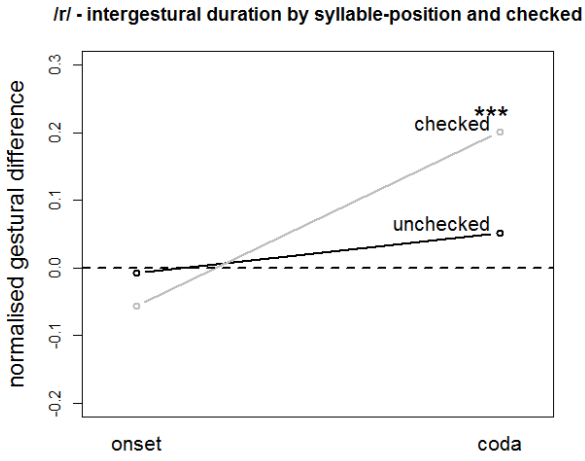
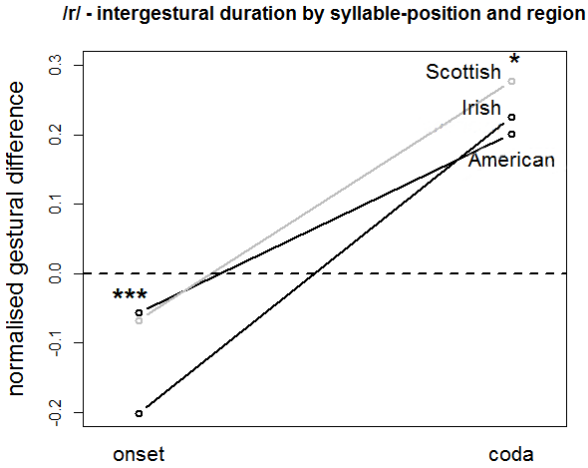


Fig. 3 shows for /r/ the same pattern of syllable-conditioned lingual gesture organisation that was observed for /l/, namely anterior gestures tend to precede posterior gestures in syllable-onset position, while the opposite pattern occurs in codas. The plot also shows a significant difference in intergestural duration depending on whether coda /r/ is preceded by a checked or a nonchecked vowel $p<0.001$; checked vowels condition greater intergestural separation. Further analysis confirmed that the posterior (root retraction) gesture for /r/ occurred significantly earlier in syllables that contained checked vowels, than in those with nonchecked vowels, $F=38.89$ $p<0.001$. Therefore greater intergestural durations in /r/ after checked vowels seem to result from early timing of the tongue-root retraction gesture in the syllable.

Fig. 4. illustrates the interaction between *syllable position* and *accent*.

Figure 4: Interaction plot for factors *syllable position* and *accent* for normalised intergestural duration in /r/.



Again, Fig. 4 shows the familiar pattern of anterior-posterior gesture organisation in onsets and codas, but also shows accent-based intergestural timing variation. Irish speakers have significantly greater intergestural durations in syllable-onset position than American, or Scottish speakers $p<0.001$, and, in coda position, Scottish speakers have significantly greater intergestural durations than Irish, or American speakers, $p<0.05$.

4. DISCUSSION

In answer to RQ 1: "**What impact do syllable position and utterance position have on the timing of lingual gestures in liquid consonants?**", we found that syllable position had a significant effect on lingual gesture timing for both /l/ and /r/. A consistent syllable-based pattern of lingual gesture organisation emerged; for liquids in syllable-onset position, anterior gestures tended to occur first, while for liquids in syllable-coda position, anterior gestures tended to occur last. This finding is in line with [8], whose cineradiographic study of American /l/ in different syllable and preboundary positions was the first to identify this symmetrical syllable-based pattern of gestural organisation. The present study shows that this pattern of gesture organisation is also present in /r/, and is found consistently across different varieties of English.

[8] also showed that longer syllable rime durations conditioned greater separation of the two lingual gestures in ambisyllabic /l/, with syllable-rime duration found to be longest, and gestural separation found to be greatest, before major prosodic boundaries. There was a similar finding in the current study; coda /l/ in utterance-final position had the greatest temporal separation between the anterior and posterior lingual gestures. We did not find similar significant effects of sentence position on gesture separation in /r/. This null result is surprising given that previous ultrasound-based research of coda /r/ in Scottish English has identified significantly delayed anterior lingual gestures for coda /r/ in utterance-final position, with anterior gesture maxima often occurring after the offset of voicing in the syllable [5]. It is perhaps significant that the /r/s in question were always of a tip-up variety, typical of working-class Scottish speech. In the current study, two thirds of participants habitually produced bunched /r/ variants in coda position. It is possible, therefore, that sentence-position effects on the timing of /l/ and /r/ gestures can be similar, but perhaps only when the /r/ variants in question are articulatorily similar to /l/, involving a tongue-tip raising gesture, rather than a dorsal or tongue-front gesture.

In answer to RQ 2: "**What is the impact of tautosyllabic vowel quality on the timing of lingual gestures in liquid consonants?**" For the three tautosyllabic vowels studied /e/, /ɪ/ and /ɛ/, we found no impact of vowel quality on /l/; however, the checked status of the tautosyllabic vowel had a significant impact on intergestural duration for /r/. It would seem that greater gestural separation occurs when /r/ follows a checked vowel, because the maximum of the root-retraction gesture occurs earlier than it does when /r/ follows nonchecked vowels. This finding shows that rhotics have a strong coarticulatory effect on the phonetically-lax checked vowels in all three varieties studied, and provides a phonetic explanation for the NURSE merger found in many varieties of English [10] [11].

Finally, for RQ 3: "**Is liquid gesture timing variation similar across different accent varieties of English?**". For /l/, we saw that Scottish speakers had significantly greater intergestural durations than American speakers, but there was no interaction between accent and other factors in the model. For /r/, speaker accent interacted with syllable-position, affecting *degree* of intergestural separation without changing fundamental patterns of gestural organisation described in the answer to RQ1. These findings suggest that syllable-based patterns of gestural organisation for liquid consonants and the increased inter-gestural separation for /l/ at utterance margins are fundamental aspects of speech production English.

5. CONCLUSION

Using ultrasound tongue imaging to systematically study intergestural timing in /l/ and /r/ in different positional conditions across three varieties of English, we have been able to show consistent symmetrical syllable-based patterns of gestural organisation for both liquid consonants. We have also shown that there is greater separation between lingual gestures for /l/ when they are in utterance-initial, and particularly utterance-final, position. These findings increase our understanding of how syllable-based allophony emerges [8] and suggest a mechanism for coda liquid weakening in utterance-final positions. We also suggest that use of tip-up or bunched variants of /r/ might affect tongue gesture timing. Previous research has shown a link between gesture timing and these two tongue shapes, see [5] and [6], but based only on the study of two sociolects of the same variety of English. More research is required to determine the impact of /r/ tongue shape on gesture timing.

6. REFERENCES

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[1] The term "checked" refers to the phonotactic specification that vowels do not occur in stressed open word-final syllables, i.e. they must always be followed by a consonant in stressed syllables. Checked vowels tend to be phonetically more lax than unchecked vowels and are also phonemically short in American and Irish English, though not in Scottish English, where vowel length is not phonemic [7].