Exploring Articulatory Characteristics of Linking /ɹ/ in British English

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Abstract

This study reports on the continuing investigation into the articulatory-acoustic nature of the linking /ɹ/ in British English. The linking /ɹ/ gesture was compared with the word-initial /ɹ/ gesture, using the EMA data collected from MOCHA-TIMIT. The results show that the linking /ɹ/s involve a smaller degree of tongue displacement and shorter articulatory durations than the word-initial /ɹ/s. This variation is closely related to the tongue configuration. The tip-up gesture of the linking /ɹ/ limits coarticulatory directionality to the horizontal dimension but the tip-down gesture to the vertical dimension. The results are discussed in terms of prosodic-positions and articulatory tasks.
Index Terms: Linking /ɹ/, EMA, coarticulation

1. Introduction

This exploratory study focuses on the articulatory characteristics of the linking /ɹ/ across word boundaries in British English. In standard British English and non-rhotic varieties of accent, a postvocalic /ɹ/ is not pronounced when followed by a word beginning with a consonant (e.g. *car park* [kɑ: pɑ:k]) but is pronounced when followed by a word beginning with a vowel (e.g. *car engine* [kɑ:ɹ endʒɪn]). This phenomenon is called linking /ɹ/. Linking /ɹ/ constitutes a part of the r-sandhi or r-liaison phenomenon which includes the intrusive /ɹ/ (e.g. *idea* [ɹ] *of*) and has been investigated from the point of view of phonetics and phonology (e.g. [1], [2], [3], [4]), sociolinguistics (e.g. [5]), and hiatus resolution (e.g. [6], [7]).

Compared to what we know about the word-initial /r/ (e.g. *research*), we have little knowledge about the articulatory characteristics of the linking /ɹ/. It is generally recognized that the word-initial /ɹ/ involves a primary constriction in the oral cavity and a secondary constriction in the pharyngeal cavity (e.g. [8]). Also, the tongue configuration varies from 'bunched/tip-down' to 'retroflexed/tip-up' (e.g. [9]). Are these features equally observed for the linking /ɹ/? What kind of features (if any) would differentiate the linking /ɹ/ gesture from the word-initial /ɹ/ gesture? These questions are explored in this paper. The production characteristics of the linking /ɹ/ are discussed in the light of prosodic positions [10] and constraints on 'articulatory tasks [11]'.

2. Method

2.1. Data collection and coding

The MOCHA-TIMIT database [12], which comprises articulatory (EPG, EMA, laryngograph (Lx)) and acoustic data of 460 sentences read by native speakers of English, was used for data collection. This study investigates the selected utterances spoken by three speakers of Southern British English referred to as SE (female), SA (male), and AP (male).

Collecting the speech materials took two steps. First, the potential linking /ɹ/ contexts were identified by an automatic search of relevant spellings appearing in the MOCHA 460 sentences (e.g. 'er' in *higher*, 'ur' in *your*). The cases followed by a space and a vowel letter were extracted. This process produced 70 potential contexts of a linking /ɹ/ across word boundaries (e.g. *numbe[ɹ] of, fo[ɹ] hours, you[ɹ] interview*). Similarly, searching the word-initial /r/s preceded by a space and a vowel letter yielded 18 tokens (e.g. *The rich, occasionally reads, to wrap*). Secondly, those 70 potential contexts of a linking /r/ were analyzed using auditory and acoustic methods. All the cases identified as containing a linking /ɹ/ were confirmed by examining a low F3 or trough on the spectrogram. The number of the linking /ɹ/ realizations varies with the speakers. 12 instances (17%) were found for SE, 51 instances (72%) for SA, and 32 instances (45%) for AP.

In order to examine the effects of linguistic features, each vowel flanking the linking /r/ was coded by the backness (front, central, back) and height (close, mid, open).

2.2. Measurements

The measurements of the articulatory data were conducted where tokens of word-initial /ɹ/ and linking /ɹ/ were realized.

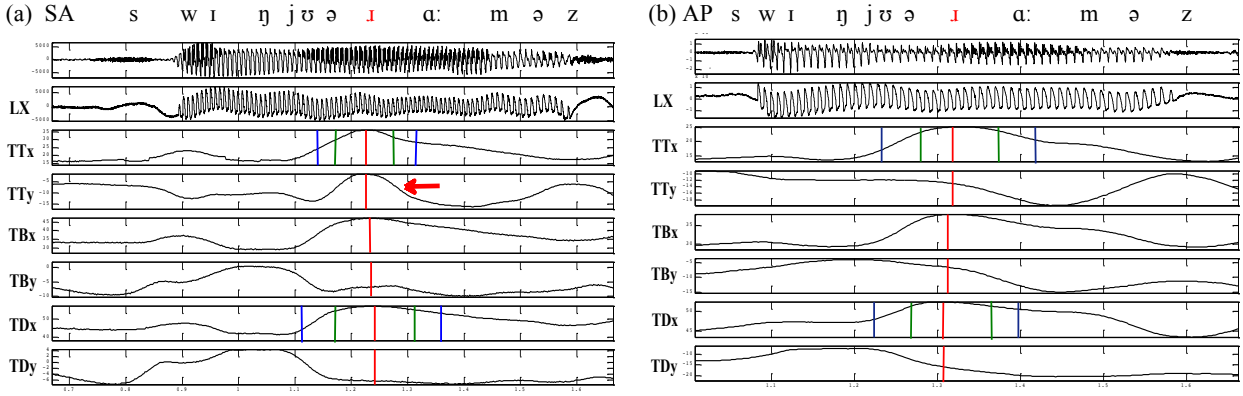

Figure 1: *Measurement points for TT, TB, and TD trajectory*

Figure 1(a,b) are representative examples of linking /ɹ/ in the sentence 'Swing you[ɹ] arms as high as you can.' Figure 1 also illustrates the measurement points used.

For the analysis of spatial characteristics, the horizontal (x) and vertical (y) displacements were recorded for the tongue tip (TT), tongue body/middle (TB), and tongue dorsum (TD) at the tangential velocity minimum point (the red line in Figure 1). The TT coil was placed 7-10mm back from the extended tongue tip, the TB coil was placed 20-30mm back from the TT coil, and the TD coil was placed 20-30mm back from the TB coil.

Temporal characteristics were analyzed for the movement of the tongue tip and the tongue dorsum. The duration measurement in this study was based on the four time points (onset, target, release, release offset) proposed by [13]. These points were specified at 20% ([14]) of the tangential velocity peak associated with movement towards, or away from, a target constriction. The two articulatory durations were identified. The *total* duration is the time interval between the onset and the release offset of a given movement (an interval marked by blue lines in Figure 1). The *plateau* duration is the interval between the target and the release of a given movement (an interval marked by green lines in Figure 1).

Statistical comparisons (t-test and one-way ANOVAS) were performed, using SPSS©, separately for the two speakers SA and AP. SE was excluded since the number of linking /r/ tokens was small.

3. Results

3.1. Linking /ɹ/ vs. word-initial /ɹ/

3.1.1. Identifying the gestures

Before presenting the results, it would be worthwhile to point out some characteristics captured in Figure 1(a,b). At the velocity minimum point (marked by a red line), all the three coils, TT, TB, TD, reveal a certain amount of retraction (i.e. the distinctive movement in the x dimension). However, the raising of the TT (i.e. the distinct movement in the y dimension, TTy, indicated by an red arrow in Figure 1(a)) is found in SA's production only. This feature, which typifies individual differences, will be clarified below.

3.1.2. Spatial aspects

Figure 2 presents all the measurements of the horizontal (x) and vertical (y) displacement of TT, TB, TD for the linking /ɹ/ and word-initial /ɹ/ for the three speakers. The general trend is that

Table 1: *Mean displacement of linking and initial /ɹ/* (mm)

		SA (s.d.)	AP (s.d.)
TTx	Linking r	**28.7** (2.3)	28.1 (1.3)
	Initial r	**32.8** (4.2)	26.5 (3.1)
TTy	Linking r	-1.1 (1.9)	-8.6 (1.9)
	Initial r	-0.2 (0.8)	-10.0 (1.7)
TBx	Linking r	**41.6** (1.9)	40.3 (0.9)
	Initial r	**44.5** (2.9)	39.4 (2.1)
TBy	Linking r	-2.0 (1.5)	-7.7 (1.5)
	Initial r	-3.7 (1.9)	-9.3 (3.0)
TDx	Linking r	**53.7** (2.1)	53.9 (1.2)
	Initial r	**56.5** (1.8)	52.7 (2.0)
TDy	Linking r	**-2.0** (1.7)	**-14.7** (1.2)
	Initial r	**-4.6** (1.9)	**-17.5** (3.2)

*For SA, initial r, n=4; linking r, n=12, and for AP, initial r, n=4; linking r, n=8.

the plot pattern for the linking /ɹ/ is not substantially divergent from that of the word-initial /ɹ/ within a speaker. However, clear patterns emerge between the speakers. The TT position is kept higher in SA's productions but is lower in AP's production. It is difficult to specify the exact tongue shapes based on the EMA data but the differences captured in Figure 2 can be labeled as the tip-up gesture for SA and as the tip-down gesture for AP.

To examine whether the tongue positions of the linking /ɹ/ are different from those of the word-initial /ɹ/, the tokens whose flanking vowels are schwas (including a diphthong [əʊ]) were selected: e.g., for the linking /r/, *December and*, *are open*, *Regular attendance*; for the word-initial /r/, *a romantic*, *the rose*. The mean displacement of the TT, TB, TD is given in Table 1. Each position of the tongue was separately examined by t-test (2 tailed). Significant differences are marked red in Table 1.

For SA, the tongue tip and body is significantly more retracted (but not raised) for a word-initial /ɹ/ than for a linking /ɹ/, and the tongue dorsum is more retracted and raised for a word-initial /ɹ/: TTx [t=-2.495, df=14, p=0.026], TBx [t=-2.326, df=14, p=0.036], TDx [t=-2.474, df =14, p=0.027], and TDy [t=2.552, df=14, p=0.023]. For AP, the tongue dorsum is more raised for a word-initial /ɹ/: TDy [t=2.268, df=10, p=0.047].

These results suggest that there is a difference between a linking /ɹ/ and a word-initial /ɹ/ on the one hand and a difference between the tip-up and the tip-down configuration of the tongue on the other.

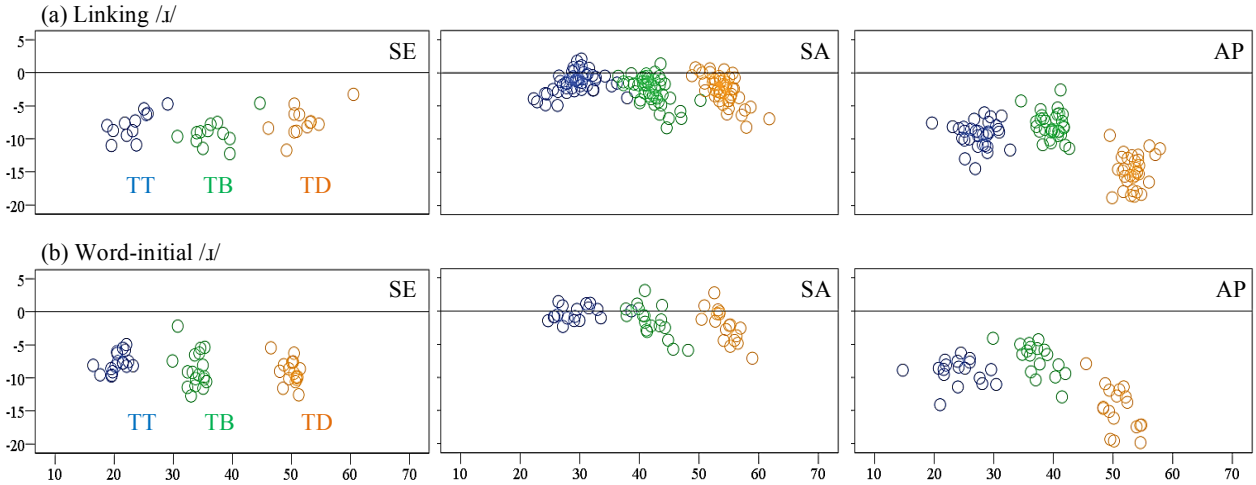

Figure 2: *TT, TB, and TD displacement of linking /ɹ/ and word-initial /ɹ/ for the three speakers* (mm)

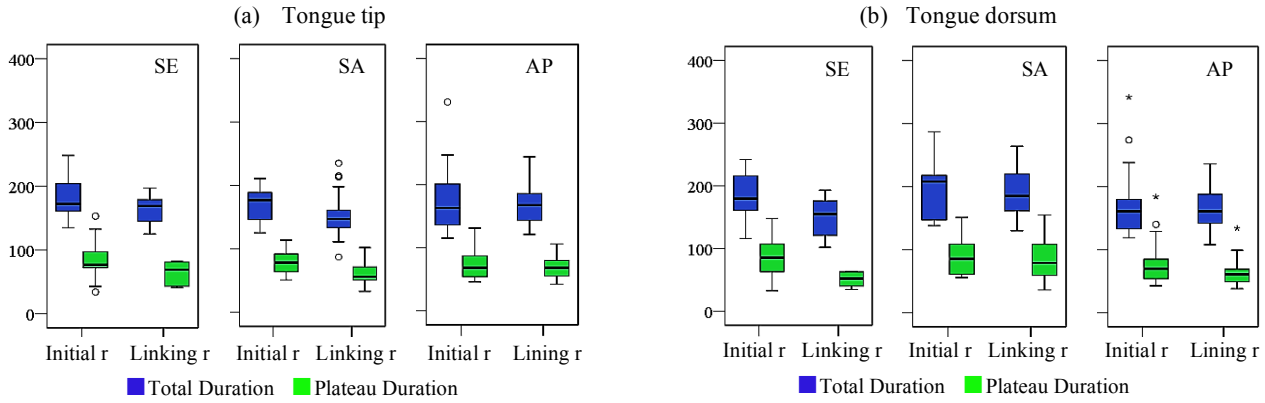

Figure 3: *Mean total and articulatory plateau duration of linking /ɹ/ and word-initial /ɹ/*

3.1.3 Temporal aspects

We now move on to the temporal aspects of the linking /ɹ/ and the word-initial /ɹ/. Figure 3 (a,b) summarizes the mean total and articulatory plateau durations of the tongue tip and the tongue dorsum for the three speakers. The three speakers show a general trend that the two durations of the linking /ɹ/ are shorter than those of the word-initial /ɹ/. Comparisons were made separately for SA (linking /ɹ/, n=39; word-initial /ɹ/, n=18) and AP (linking /ɹ/, n=26; word-initial /ɹ/, n=18) by t-test (2 tailed).

SA shows a significant difference in the durations of the tongue tip gesture (TT total [t=-2.577, df=55, p=0.013] and TT plateau [t=-3.714, df=55, p<0.0001]), but not in those of the tongue dorsum gesture (TD total [t=-0.456, df=55, p=0.650] and TD plateau [t=-0.595, df=55, p=0.554]). Thus, the duration of the tongue tip retracting (and raising) gesture is shorter in the linking /ɹ/ but not that of the tongue dorsum gesture.

In contrast, AP reveals no significant differences: for the tongue tip, TT total [t=-0.567, df=42, p=0.574] and TT plateau [t=-0.676, df=42, p=0.503]; and for the tongue dorsum, TD total [t=-0.875, df=42, p=0.387] and TD plateau [t=-1.702, df=42, p=0.96]. It might be possible to assume that this result is related to the configuration of the /ɹ/ gesture used by speaker AP. However, there is still too much uncertainty to confirm such an interpretation. Further research is necessary on this point.

3.2. Effects of V2 backness and height on the TT, TB, TD displacements of linking /ɹ/

In order to further explore the articulatory nature of the tip-up (SA) and the tip-down (AP) gesture, the effects of the backness and height of the following vowels (V2) was examined. In this analysis, the vowel preceding the linking /ɹ/ (V1) is fixed to a schwa (including [ʊə] and [eə]): e.g., *for eating, sculpture in, ever enter, power outage, their own, thermometer under, paper and, Her auburn, oyster on*. We will examine how the two kinds of linking /ɹ/ gesture accommodate to coarticulatory effects of the changing V2s.

Table 2 summarizes the mean displacements in terms of the backness categories and Table 3 in terms of the height categories. The results of one-way ANOVAS are also presented in the right-most column of each table and significant differences are marked red.

In the productions by SA, as shown in Table 2(a), the V2 backness effects were found to be significant in the horizontal dimension of the tongue body and dorsum (TBx, p=0.045; TDx, p=0.033). The TB and TD of the linking /ɹ/ are more retracted when followed by a back vowel than when followed by a front or central vowel. Note in passing that the horizontal movement of the tongue tip (TTx) is virtually significant (p=0.058). In contrast, as summarized in Table 3(a), no significant

Table 2: *Mean displacement and effects of V2 backness* (mm)

(a) SA

	Front (s.d.)	Central (s.d.)	Back (s.d.)	F(2,42)
TTx	28.3 (2.8)	29.0 (2.3)	31.2 (4.2)	3.05
TTy	-1.6 (1.6)	-1.0 (1.8)	-1.8 (1.1)	0.83
TBx	41.0 (2.0)	41.8 (2.0)	43.5 (3.7)	**3.35**
TBy	-2.1 (1.2)	-2.2 (2.0)	-3.7 (2.7)	2.61
TDx	53.4 (1.9)	53.6 (2.0)	55.7 (3.4)	**3.71**
TDy	-2.0 (1.4)	-2.3 (2.0)	-3.6 (3.2)	2.13

(b) AP

	Front (s.d.)	Central (s.d.)	Back (s.d.)	F(2,25)
TTx	26.9 (3.7)	28.0 (1.6)	27.1 (2.6)	0.47
TTy	-9.0 (1.4)	-9.3 (2.3)	-10.1 (2.2)	0.55
TBx	39.0 (2.2)	40.2 (1.1)	39.5 (1.9)	1.50
TBy	-7.8 (2.1)	-7.7 (2.4)	-7.8 (1.0)	0.01
TDx	52.6 (2.0)	53.7 (1.7)	53.0 (1.2)	1.08
TDy	-14.1 (2.7)	-14.9 (2.3)	-15.6 (1.3)	0.82

*For SA, front, n=22; central, n=14; back, n=9; For AP, front, n=10; central, n=12; back, n=6

Table 3: *Mean displacement and effects of V2 height* (mm)

(a) SA

	Close (s.d.)	Mid (s.d.)	Open (s.d.)	F(2,42)
TTx	27.7 (3.4)	29.2 (2.4)	30.2 (3.3)	2.62
TTy	-1.8 (1.8)	-1.0 (1.7)	-1.7 (1.2)	1.30
TBx	40.6 (2.3)	41.8 (1.9)	42.6 (2.9)	2.54
TBy	-1.9 (1.1)	-2.2 (1.5)	-3.2 (2.5)	2.10
TDx	52.9 (2.2)	53.9 (2.2)	54.7 (2.6)	2.05
TDy	-1.8 (1.3)	-2.1 (1.8)	-3.2 (2.7)	1.85

(b) AP

	Close (s.d.)	Mid (s.d.)	Open (s.d.)	F(2,25)
TTx	25.7 (4.3)	28.1 (1.8)	27.6 (2.1)	1.77
TTy	-8.6 (1.6)	-9.0 (1.8)	-10.1 (2.2)	1.64
TBx	38.2 (2.6)	40.1 (1.2)	39.8 (1.4)	2.89
TBy	-7.3 (2.4)	-7.8 (1.4)	-8.0 (2.4)	0.23
TDx	52.4 (2.6)	53.7 (1.2)	53.1 (1.7)	1.04
TDy	-12.4 (1.7)	-15.0 (1.4)	-15.8 (2.5)	**6.00**

*For SA, close, n=13; mid, n=16; open, n=16; For AP, close, n=6; mid, n=11; open, n=16

differences were found for the effects of the V2 height.

Conversely, AP indicates a significant difference in the effects of the V2 height but not in those of the V2 backness. As seen in Table 3(b), the significant difference is limited only to the vertical dimension of the tongue dorsum (TDy, p=0.007). The dorsum is significantly higher when followed by a close vowel than when followed by a mid or open vowel.

4. Discussion

We have so far investigated the spatiotemporal characteristics of the /ɹ/ gesture in the production of a linking /ɹ/ and a word-initial /ɹ/. The results presented above are summarized as follows: (i) the constrictive approximation for a linking /ɹ/ is similar to that for a word-initial /ɹ/. One speaker (SA) tends to use the tip-up configuration and the other speaker (AP) the tip-down configuration. (ii) The TT, TB, TD displacements of a linking /ɹ/ are smaller in degree than those for a word-initial /ɹ/. This variation is restricted to the horizontal dimension in the tip-up articulation and to the vertical dimension in the tip-down articulation. (iii) In the tip-up production, the total and articulatory plateau duration of a linking /ɹ/ is shorter in the TT gesture (but not in the TD gesture) than that of a word-initial /ɹ/, while such durational variations are not significant in the tip-down production. And (iv) for the coarticulatory effects of the following vowel (V2) on the linking /ɹ/ gesture, the effects of the V2 backness (but not height) is significant in the tip-up production (SA) and the TB and TD gesture is more retracted when followed by a back vowel than when followed by a front or central vowel. In contrast, in the tip-down production (AP), the effects of the V2 height (but not backness) is significant and only the TD gesture is more raised when followed by a close vowel than when followed by a mid or open vowel.

Here we shall focus on the spatial differences between the linking /ɹ/ and the word-initial /ɹ/. This can be interpreted as the effects of the position-related, or the domain initial, articulatory strengthening [10]. The spatial positioning becomes more extreme in the production of word-initial /ɹ/s. However, it is evident in the results given in Table 1 that such a strengthening is not applied equally to the two dimensions of a given gesture. The tip-up type constriction gesture allows the strengthening in the horizontal (x) dimension of the tongue but not in the vertical (y) dimension. In contrast, the tip-down constriction gesture accepts the strengthening of the tongue dorsum in both dimension, but not that of the tongue tip and body. Similar results are obtained for the effects of V2 backness and height in the production of linking /ɹ/s (Tables 2 & 3). The results reflect the distinctive properties of the tip-up and tip-down gestures, as well as the position-related spatial variation and the V2 backness/height-related effects.

Why do the tip-up and the tip-down constrictions differ in their realization of the position-related effects and the V2 coarticulatory effects? Given that the F3 lowering is a distinct characteristic of /ɹ/ and is a front cavity resonance [15], both constriction gestures aim at making a space in the front of the oral cavity. Coarticulatory directionality limited to a single dimension of the articulatory movement, therefore, could be interpreted as one realizational strategy specific to the given constriction. This assumption will be substantiated by further research of an articulatory-acoustic analysis of the linking /r/ and the word-initial /r/.

Finally, some comments should be made regarding speaker SE's phonetic realizations in the potential linking /ɹ/ environment. In the process of extracting the linking /ɹ/ tokens, variable realizations were coded by the following four categories: (i) linking /ɹ/, (ii) hiatus, (iii) glottalized, and (iv) other. The glottalized realizations, which are subcategorized into 'glottal stop and creaky voice,' are the commonest in SE's production (60%, 42/70 tokens). Also, AP shows 'other' patterns (e.g. a weak vowel/syllable deletion) more frequently than the other speakers (29%, 20/70 tokens). The issue of hiatus resolution, which involves speakers' strategies to create a smooth transition, will be investigated in future research.

5. Conclusions

The current study has explored the articulatory nature of the linking /ɹ/ productions across word boundaries in British English. This study has used the data collected from the multichannel articulatory database. Controlled experiments are also necessary to substantiate the articulatory patterns we have explored. It is hoped, however, that the parametric phonetic analysis presented in this study provides another interesting description of the linking /ɹ/.

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