Original Paper

Phonetica 2002;59:38–48

Received: October 12, 2000
Accepted: March 12, 2001

An X-Ray Investigation of Pharyngeal Constriction in American English Schwa

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Abstract

A study of early X-ray footage of 4 subjects was conducted to test the prediction that there may be a midpharyngeal constriction in American English schwa. Results show a significant constriction during schwa relative to lingual rest position for all 4 speakers. This evidence contradicts views of American English schwa as having no articulatory target or place features, as well as those which have suggested a neutral target throughout the vocal tract. These findings, however, support claims connecting English schwa with reduced /r/. In addition to the basic effect 1 subject showed a bimodal pattern in schwa, which may indicate that this subject has distinct schwas in lexical vs. functional words, a property that has also been observed with respect to /r/ in r-vocalizing dialects.

1. Introduction

The English schwa has always been something of a mystery, both in terms of its phonological representation and its articulatory properties. One persistent assumption regarding English schwa has been that it lacks an articulatory target, e.g.: '[English schwa is] produced with a neutral setting of the articulators and is in this respect a 'minimal' vowel, involving, as it does, no displacement of the articulators from the neutral position' [Giegerich, 1992, p. 68]. Another is that it lacks featural content, e.g.: '... schwa is an empty slot unassociated ... with any melody segment ...' [Halle and Mohanan, 1985, p. 82]. Confirming or disproving these claims has been less straightforward than one might expect: Schwa cannot, by definition, be held for a duration sufficient to produce satisfactory MR images which could show the entire length of the vocal tract, and while more dynamical point-tracking devices such as X-ray microbeam have been used [Browman and Goldstein, 1992], these are limited to the anterior regions of the tongue. Moreover, even if it is true that schwa is produced with a truly 'neutral' articulatory setting, the question remains as to whether this neutral setting constitutes an active 'target' [Browman and Goldstein, 1992] or if it is simply a recoil

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to the default 'rest' position for the articulators during speech, 'identical with the relaxation position of the vocalic functional system' [Barry, 1992, p. 66] (see section 2.3 for further discussion of the notions of rest position and functional system as used in this paper). The present paper uses data from X-ray motion pictures to question whether the tongue position for American English schwa is neutral in the pharyngeal region, and whether there is further need to consider schwa as having an active articulatory target.

1.1. A Neutral Position?

In an X-ray microbeam study, Browman and Goldstein [1992] observe that, during productions of American English schwa flanked by identical full vowels [e.g., CVCəCVC(ə)], two points on the tongue (roughly in the palatal and velar regions) appeared to move actively toward a 'neutral' goal – one which approximated the average positions of the articulators for all of the vowels in the system[1]. Though the interpretation of this as movement toward an active articulatory target is not without controversy, at least in cases where flanking vowels are not identical [Kingston, 1992], the descriptive observation is not disputed: In its oral component, American English schwa appears to have a 'neutral' position. It is unclear, however, whether this neutral configuration persists in the parts of the tongue posterior to these. In fact, quite to the contrary, historical and phonological alternations involving schwa and /r/ have prompted predictions of a pharyngeal constriction[2] in English schwa [McMahon et al., 1994, pp. 303–304; Gick, 1999]. This proposal is summarized in the following section.

1.2. The Connection between Schwa and /r/

Under most views of phonology, English schwa can derive from a number of different sources. In some cases, schwa alternates with other vowels (e.g., *mora* vs. *moraic* /e(j)/, *drama* vs. *dramatic* /æ/, etc.), suggesting that these schwas are simply reduced full vowels, as they appear in unstressed syllables. In the case of function words, schwa seems to constitute an extreme version of this category, where most or all of entire words can be reduced to schwa (e.g.: *the* < /-i(j)/; *ya* < /-u(w)/; *a* < /e(j)/; *shoulda* < /hæv/; *kinda* < /ʌv/; *wanna* < /tuw/; etc.) [McCarthy, 1993]. In contrast to these, some words seem to contain lexical schwas, which do not alternate with other vowels (e.g., *about, banana*). Finally, in some dialects, schwa can result from the loss of a historical syllable-final /r/. This paper is concerned with the three latter types of schwa: reduced schwa in function words, lexical schwa, and /r/-schwa.

It is a well-known fact of English that in certain dialects, postvocalic /r/ undergoes reduction, or 'vocalization' [Jones, 1989]. When vocalization of /r/ takes place following a nonlow vowel, the historical /r/ is said to be replaced with schwa, as shown in (1). As described by one linguist: '... English /r/ before a consonant or [in final position] is reduced ... In Southern British speech this *r* ... is replaced by [ə] in words like *fear, fair, fire, floor, boor,* or in *fierce, fairs, fires, floors, boors*' [Heffner, 1950, pp. 149–150].

[1]When flanking vowels were not identical in the Browman and Goldstein [1992] study, it appeared that the tongue position during the schwa was transitional between the positions it occupied during the full vowels.
[2]'Pharyngeal constriction' here and henceforth refers to a midline constriction in the mid- and upper pharynx (from about the top of the epiglottis upward to just below the uvular region), due mainly to a retraction of the tongue root.

(1) Vocalization of /r/ following nonlow vowels in Received Pronunciation (the prestige dialect spoken throughout much of Southeastern England)

here *hiɹ > [hiə]
hair *hɛɹ > [hɛə]
sure *ʃuɹ > [ʃuə]

Another historical connection between /r/ and schwa is implicated in a description of early 20th-century RP English by phonetician Daniel Jones [1928, p. xvii], who observed that many speakers of that dialect insert a historically unattested /r/ 'at the end of every ... word terminating with «ə». These pronounce *the idea of it* «ðiaiˈdiərəvit»'. This phenomenon has since become known as 'intrusive r', and is now quite widespread in various incarnations in many dialects of English. Because of these connections between /r/ and schwa, numerous scholars have identified schwa as a key component in otherwise theoretically quite different explanations of intrusive r [e.g., Halle and Mohanan, 1985; McMahon et al., 1994; Giegerich, 1997; Gick, 1999].

One hypothesis, first suggested by McMahon et al., [1994] and further pursued by Gick [1999], suggests a possible explanation for this connection between English schwa and /r/, as follows: It has long been known that /r/ in many dialects of English comprises multiple articulatory gestures, including tongue front/tip raising [Hagiwara, 1995; Westbury et al., 1998] and tongue root retraction [Delattre and Freeman, 1968; Alwan et al., 1997][3]. The McMahon et al. [1994] hypothesis proposes that, if the anterior raising gesture of /r/ were removed, the remaining tongue configuration would closely resemble the articulation of schwa. Gick [1999] takes this proposal a step further, arguing that all final schwas in lexical words (in r-intruding dialects only) are simply the final allophones of /r/ [see Gick et al., 2000, for MRI evidence on this point]. Both the original hypothesis proposed by McMahon et al. [1994] and its extension proposed by Gick [1999] support the basic prediction that an /r/-like pharyngeal constriction should be found in schwa, at least in r-intruding dialects.

Adding plausibility to this hypothesis is the reasonably well-established observation that certain (particularly anterior) consonant gestures undergo a magnitude reduction (i.e., a reduced degree of constriction) in postvocalic allophones. This 'final reduction' phenomenon has been reported for the tongue and lip gestures of stop consonants [Turk, 1994; Browman and Goldstein, 1995; Keating et al., unpubl.], nasals [Browman and Goldstein, 1995], /l/ [Giles and Moll, 1975; Ash, 1982; Hardcastle and Barry, 1989, p. 15; Sproat and Fujimura, 1993; Gick, in press], and glides [Gick, in press]. Importantly for the present discussion, this reduction has also been observed in the anterior raising gesture of American English /r/ [Gick, 1999].

This phonological and phonetic evidence thus seems to conspire in support of the McMahon et al. [1994] hypothesis. The final step in confirming or disconfirming this hypothesis, however, will be to test directly for the presence of the predicted pharyngeal constriction in English schwa. If this pharyngeal component is present in schwa, it will contradict at least two of the positions presented above in section 1: First, that schwa has a 'neutral' configuration throughout the vocal tract; second, that, neutral or not, schwa lacks an articulatory target.

[3]Lip rounding or adduction is likely to be another important component of /r/, depending on dialect. However, this additional factor has been largely ignored in previous studies of /r/, and will be addressed in a future study.

The remainder of this paper reports on a study conducted to test this hypothesis by comparing the midsagittal width of the pharynx during utterances of American English schwa with those of other vowels and during pauses between speech. Since, as discussed above, measurement of the pharynx during production of schwa is less than straightforward, the present study draws upon early X-ray motion picture footage of speakers of American English.

2. Methods

A study of X-ray footage was conducted to test the specific hypothesis that there is a greater degree of pharyngeal constriction during production of American English schwa than for rest position of the articulators. The term 'rest position' here refers to the default position of the 'functional system' of speech (the default position of the articulators during speech, as opposed to that of quiet respiration, etc.) [Barry, 1992, p. 66].

2.1. Materials

A video copy of an early pilot X-ray motion picture made at Haskins Labs [Cooper and Abramson, 1960] was obtained. The video depicts sagittal views of 4 subjects producing a variety of utterances. It is apparent from the film that subjects' heads were well stabilized, and that each subject remained at a fixed distance from the X-ray machine throughout the experiment. The midline of the tongue was coated with barium sulfate paste, and the superior surface of the palate was coated somewhat with a radio-opaque oil sprayed through the nose.

Manipulations to the original X-ray sequences were as follows [Arthur Abramson, personal commun.]: To facilitate analysis, the films were slowed by a factor of 3 by running the camera used to film the image-end of the X-ray intensifier 3 times faster than normal speed for 16-mm film. The audio signal was similarly slowed using a 19-channel vocoder and a 22-track variable speed tape recorder. One track of the tape recording was taken up with a synchronization signal to monitor the camera speed for use in editing the audio and video tracks. In addition, at the beginning of each run, a solenoid cell was discharged within camera view to provide a synchronization point with the audio track.

2.2. Subjects

Four native speakers of American English participated in the X-ray film, 3 male and 1 female. All subjects were phonetically trained. According to the coordinator of the original X-ray film project [Arthur Abramson, personal commun.], the native dialect regions of the subjects were as follows: subject 1 (male), unknown (NE US); subject 2 (male), NE New Jersey; subject 3 (male), Illinois; subject 4 (female), Western Massachusetts.

2.3. Tokens

Pharynx width was compared for utterances of schwa, rest and the control vowels /a/ and /i, u/. The latter were used to establish the functional range of width in the mid-pharynx, with /a/ used to determine an approximate maximum pharyngeal constriction, and /i, u/ (combined) used to represent a maximum pharyngeal opening (see section 2.4 below for details regarding the actual measures taken).

Tokens of schwa, rest, and the control vowels were taken both from isolated nonsense words and syllables and from full English sentences produced in the X-ray film. The number of tokens and repetitions produced in the original film varied from subject to subject. In addition, as the original X-rays were made to illuminate the front of the mouth rather than the pharynx, and as films were made at different exposures, some are too dark in the areas of interest for pharyngeal wall and tongue shape to be resolved (especially for subject 1). For these reasons, the number of tokens measured for each subject varied as shown in table 1.

Productions of schwa were taken from word-initial and word-final positions, in nonsense word sequences [árə, írə, úrə] and [əpá, əpí, əpú], [əbá, əbí, əbú], [əmá, əmí, əmú], and in the word *the* in the phrases *The good man* ... and ... *in the bay* ... Productions of control vowels /a, i, u/ were taken from the same nonsense sequences, as well as sequences [pa, pi, pu], [ba, bi, bu], [ma, mi, mu], [ta, da, na].

Table 1. Number of tokens recorded for each subject

Subject	Schwa	Rest	/a/	/i, u/
1	7	7	7	7
2	22	22	16	22
3	10	10	10	14
4	5	5	7	4

[at, ad, an], [ap, ab, am], and one sentence context (/i/ in ... *a large eel* ...). Rest was determined as any period of at least several frames long between utterances where no sound was being produced, and where the articulators appeared to drift to an approximately medial position (i.e., where it did not appear that the vocal tract was carrying over or anticipating surrounding articulations), but where the vocal tract otherwise remained in a functional speech mode (as opposed to quiet breathing, swallowing, throat-clearing or other nonspeech modes).

2.4. Analysis

Relevant segments of the video were isolated, then digitized using Adobe Premier 4.2 digital video editing software running on a Power Macintosh 7300/180. From these, individual frames were chosen and extracted as PICT files. Frames were chosen at the extremum of the pharyngeal movement associated with each acoustic event. Where no extremum was apparent, a visually clear frame was chosen from near the end of the acoustic event, so as to capture the position of the articulators at a point where the intended configuration had presumably been reached.

After frames were selected and extracted, those that were too dark were converted to gray scale and the darkness levels adjusted using Adobe Photoshop 5.0. In some cases, structures were additionally made more discernible using the public domain NIH Image 1.62 program (developed at the US National Institutes of Health, available at http://rsb.info.nih.gov/nih-image).

Where necessary, images were rotated using NIH Image so that the pharynx wall was vertical; stable bone points in the maxilla, upper teeth and palate were used to ensure an identical head angle across all images for each subject. The distance of the head from the camera was apparently constant within subject, so all images were presumably of the same scale; this was verified using the bone points as mentioned above.

Once images were extracted, lightened and rotated, pharynx width was measured using NIH Image measuring tools by drawing a horizontal line between the tongue root and pharynx wall at the point of average greatest constriction for the schwa and rest conditions, as shown figure 1. This measurement method was chosen because the pharyngeal constrictions for the control conditions were relatively long and uniform in width for all subjects, while within this general region of constriction, the schwa and rest conditions were very similar to one another, and represented a relatively narrow constriction location. Thus, using the schwa/rest conditions to determine measurement location allowed for a more clearly and narrowly defined and a more easily replicable measurement location. A constant measurement location was maintained within subject by using a constant vertical displacement from stable maxillary bone points (drop, in pixels, from tip of incisors). The vertical displacement of the measurement location varied across subject (subject 1: 48 pixels; subject 2: 64 pixels; subject 3: 75 pixels; subject 4: 54 pixels) depending on size of the vocal tract, angle of the pharynx relative to the maxilla (e.g., forward 'jutting' of the head), and across-speaker differences in constriction locations. The length of the resulting horizontal line was extracted in pixels, and this number was entered into a spreadsheet for each condition. Based on average anatomical dimensions of male subjects, 16.25 pixels in this study is very approximately equivalent to 1 cm.

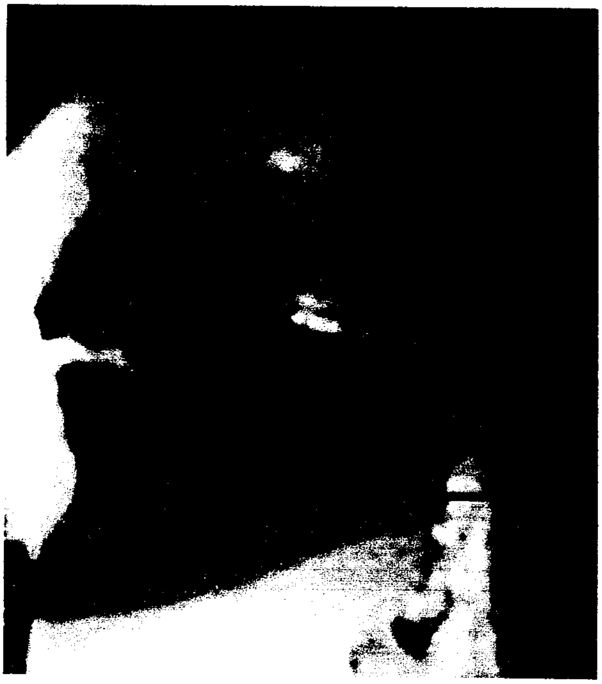

Fig. 1. Example X-ray image showing horizontal line of measurement.

3. Results

Results of analyses of variance (ANOVAs) for the 4 subjects are shown in figure 2. Main effect of vowel quality was significant ($p < 0.0001$) for all subjects; post-hoc tests (Fisher's PLSD) indicate that all categories (schwa, rest, /a/, i/u) are significantly different at $p < 0.05$. F and p values are listed in table 2.

In addition to the mean effects, standard deviation (SD) shows some interesting results. First, in general, SD is much higher for i/u than the other conditions. This is an artificial effect resulting from combining these two vowels: /i/ and /u/, though very similar, involve consistently different pharynx widths, particularly in the mid- to upper pharynx. Second, as might be expected, SD is slightly higher for the rest condition than for /a/ or schwa for subjects 1, 2 and 3. This is not surprising, as rest position is not an articulatory target *per se*, and was expected therefore to show greater variability. However, for subject 4, schwa shows a higher SD than all other conditions (schwa 3.482; rest 1.718; /a/ 1.000; i/u 2.614). Although there were fewer tokens available for this subject than for the others, which could lead to misleading distributions, this particular increase does seem to signify a potentially real distinction. If we split the schwa cases into those in full lexical items (nonsense words though they may be) and those in function words (in this case, two repetitions of *the*), we see the pattern shown in figure 3. Subject 1 and subject 2 did not show this lexical/functional distribution; no function word tokens were available for comparison for subject 3.

Here it can be seen that the mean pharynx width for the schwa in *the* (13.75) patterns closely with the mean for rest position (14.2), while the width for the full lexical

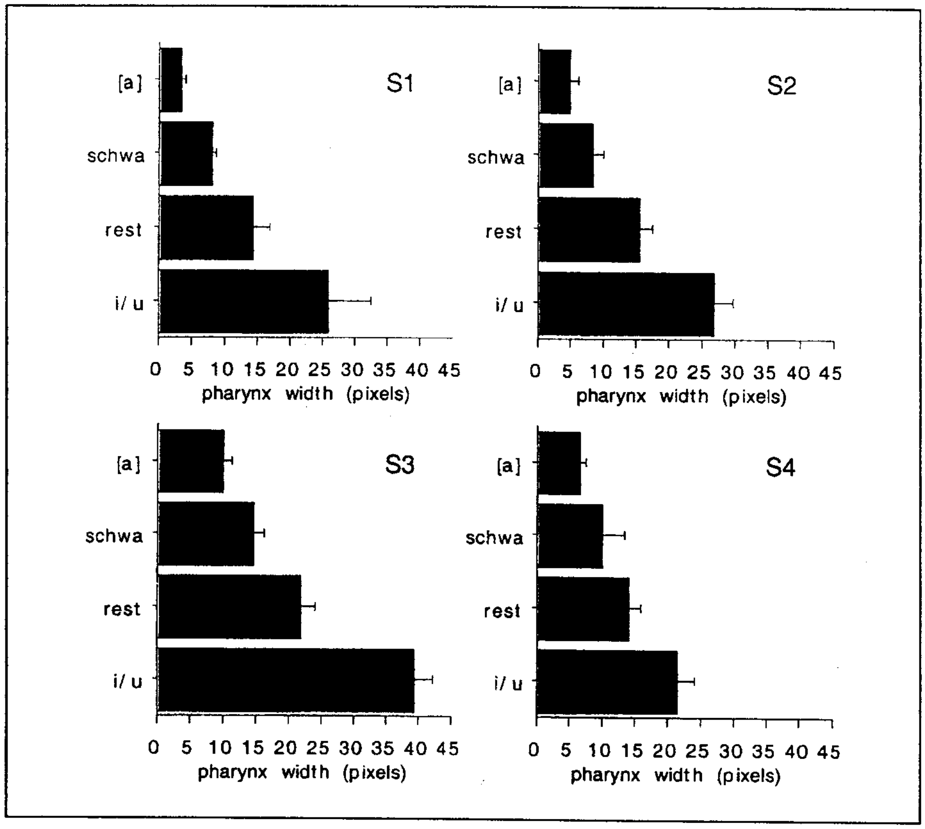

Fig. 2. Graphs of midsagittal pharynx width for 4 subjects, measured in pixels. Error bars show SD. All differences are significant ($p < 0.05$).

Table 2. Statistical table for figure 2

		Subject 1	Subject 2	Subject 3	Subject 4
Main effect	d.f.	3, 24	3, 78	3, 40	3, 17
	F	50.84	479.45	473.96	40.28
	p	<0.0001	<0.0001	<0.0001	<0.0001
Post-hoc comparisons (p)	schwa vs. rest	0.0034	<0.0001	<0.0001	0.0092
	schwa vs./a/	0.0224	<0.0001	<0.0001	0.0170
	schwa vs. i/u	<0.0001	<0.0001	<0.0001	<0.0001
	rest vs. /a/	<0.0001	<0.0001	<0.0001	<0.0001
	rest vs. i/u	<0.0001	<0.0001	<0.0001	0.0002
	/a/ vs. i/u	<0.0001	<0.0001	<0.0001	<0.0001

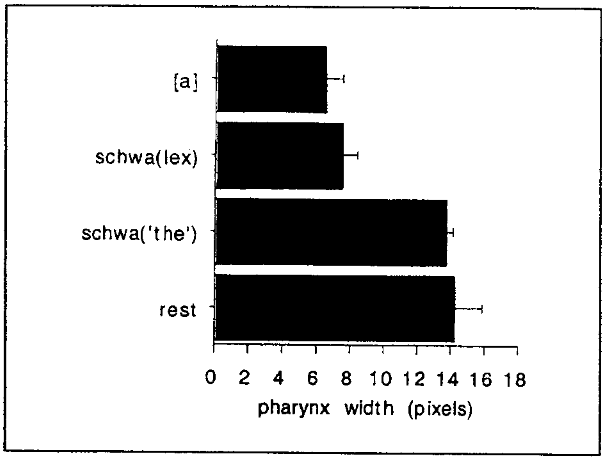

Fig. 3. Graph of midsagittal pharynx width for subject 4, showing bimodal distribution in schwa. Because of the small number of tokens, differences/similarities should not be considered significant.

schwa (7.5) is much more retracted, closer to that of /a/ (6.5). Because of the limited number of tokens for this subject, this effect cannot be considered statistically testable. However, the possibility that this is a real bimodal distribution will be discussed in the following section.

4. Discussion

The primary observation to be drawn from these results is that English schwa appears not to be targetless. Rather, for all 4 subjects there is a significant retraction of the tongue root during schwa relative to the rest position. This finding contradicts views of American English schwa as either having no target or a neutral target, and supports the connection between schwa and /r/, even in non-r-vocalizing dialects.

Before discussing subject 4 in more detail, one possible criticism of the methodology used in this study should be noted. As 'rest' position generally occurred between utterances, many of these measurements are likely to have been taken during inspiration while the others were taken solely during expiratory speech. The question should be addressed as to whether the difference between rest position and schwa could be due to general differences in the pharynx during inspiration versus expiration (i.e., is sagittal pharynx width generally greater during inspiration than expiration?). Findings on this matter indicate to the contrary that, at least in tidal breathing, axial cross sections along the entire length of the pharynx decrease significantly in area during inspiration [Schwab et al., 1993]. This effect is, however, more marked in the lateral than the anteroposterior dimension [Schwab et al., 1993], and is smallest in the retroglossal region [Trudo et al., 1998], placing it at an order of magnitude unlikely to affect the present results significantly.

Finally, returning to the possible bimodal distribution for subject 4's schwas. This effect would indicate that this subject has two completely different schwas – one (with typical tongue root retraction) that appears as a syllable peak in lexical words, and the other (showing no distinction from rest position in its pharyngeal component) restricted to function words. While there is clearly insufficient data to support calling this a demonstrated effect, it may be of some interest to consider whether there is reason to suspect an explanation. The first question to be asked about this is what is special about function words that might be relevant to these results, and second, is there independent reason to suspect that subject 4 should exhibit these special features?

Relevant to the first question, McCarthy [1993, 1999] shows that, at least in the r-vocalizing dialect of Eastern Massachusetts, intrusive r appears following all (nonglide) final vowels (ə, a, and ɔ) except for the schwa of function words (i.e., *has Buddha*[r] *eaten?*, but *he shoulda*[*r] *eaten*). In fact, our original hypothesis regarding the /r/-schwa connection predicts this lack of an intrusive r following function words in Eastern Massachusetts. Gick [1999] motivates the merger of schwa and postvocalic /r/ in r-vocalizing dialects on the grounds that both are specified for a pharyngeal constriction (or, under a more extreme view, that all final schwas in lexical words, whether historically derived from /r/ or not, in r-intruding dialects are simply the postvocalic allophone of /r/, with a reduced tongue front raising gesture). On the contrary, the schwa of function words alternates with full, stressed vowels, or even with full words in their citation forms (see examples in section 1.2 above). There is thus no reason to expect that the surface schwa present in reduced function words should be specified for the same pharyngeal constriction as the other instances of surface schwa, particularly in an r-reducing dialect where the merger between historical final /r/ and schwa can be shown to have taken place. The remaining category of surface schwa – those that alternate with full vowels in nonfunction words – is not included in this X-ray data, and is beyond the theoretical scope of this paper; this will be the subject of a future study.

In answer to the second question then, regarding the dialect of subject 4, according to Abramson [personal commun.], this subject (now deceased) was born in the early 1900s in Western Massachusetts. While this is physically close to the Eastern Massachusetts dialect referred to by McCarthy [1993, 1999], it is unlikely that this subject spoke the same dialect (though no information is known about her family background). It may, however, be observed that while the other 3 subjects in this study spoke dialects with strongly pronounced final /r/ (as in, e.g., the word *Saturday* in the film), subject 4's postvocalic /r/ was both audibly vocalized and showed no substantial tongue front raising. Because the lexical/functional word distinction pointed out by McCarthy [1993, 1999] was based on the distribution of intrusive r, there is no basis for expecting non-r-intruding dialects to exhibit a similar difference between lexical and functional words. However, this in no way rules out the possibility that a similar distinction could exist in non-r-intruding dialects.

Conclusion

This paper has provided evidence that there is a significant retraction of the tongue root during some instances of American English schwa, as compared with the lingual rest position for speech. This study has also described, therefore, an original means of interpreting and measuring 'rest position' during speech, as discussed in, e.g., Barry [1992]. The evidence for the pharyngeal constriction in schwa directly contradicts most previous views of American English schwa, some of which have treated schwa as targetless (or featureless in systems where features are intended to correspond with physical events), and others which have suggested a neutral target throughout the vocal tract. These findings also provide further support for hypotheses connecting schwa with reduced /r/ [McMahon et al., 1994; Gick, 1999]. A further preliminary finding of this paper suggests that there may be multiple different types of schwa. In particular, 1 subject showed a bimodal pattern in schwa, suggesting that this subject has distinct schwas in lexical and functional words. If future work verifies this finding, it will provide a lexical-articulatory basis for observed differences in the phonological patterning of lexical vs. functional words, such as the otherwise complex phonological dichotomy between lexical and functional words with respect to intrusive r.

Acknowledgments

The author is grateful to Fiona Campbell and Ian Wilson for assistance with data analysis, and to Douglas Whalen, Douglas Pulleyblank, an anonymous reviewer, and colloquium audiences at the University of British Columbia, University of Rochester, and Simon Fraser University for helpful discussion. Parts of this paper were presented at the 5th Seminar on Speech Production (SPS 5) in Kloster Seeon, Bavaria, Germany (May 2000). This work was supported by a grant from the Natural Science and Engineering Research Council of Canada. For all errors, poorly framed arguments, and other shortcomings of this work, the author himself is to blame.

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