IDENTIFYING AND EVALUATING APRAXIC SPEECH DEFICITS USING MAGNETOMETRY

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ABSTRACT

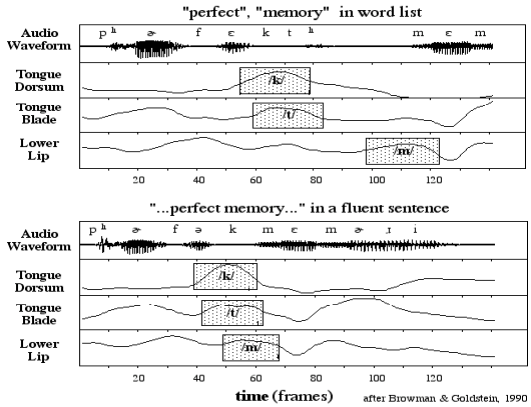
An understanding of the relationship of speech and language symptoms to lesions in the frontal region of the dominant hemisphere depends on a fuller description of the speech phenomena than can be provided by transcriptional or acoustic investigation alone. This paper provides examples of how articulatory movement tracking can aid in describing apraxic speech deficits.

1. INTRODUCTION

Loss of fluency in speaking is frequently one of the consequences of a lesion of the frontal region of the left cerebral hemisphere. The resulting impairments of language function may result in errors of two different types—articulation errors, typically characterized as apraxia of speech, and syntax errors, typically characterized as agrammatism. Analysis of the articulatory deficits in patients has been almost entirely indirect. Experiments have evaluated transcriptional and acoustic records in order to identify and characterize the speech deficits, with the output phones described by such adjectives as normal, distorted, omitted, or metathesized. Though such perceptual techniques have a number of well-documented weaknesses (see [6, 7, 12]), very few studies have investigated the source of the acoustic, and by extension, the transcriptional data—namely, the articulatory behavior. The central concern of this research note is to describe what type of information might be gained regarding apraxic speech through the use of articulatory movement tracking.

There is general agreement that the articulation errors in apraxic patients consist in large measure of a failure of appropriate timing relations in coordinating the articulators. Acoustic studies of VOT in apraxic speech have contributed to this understanding (e.g. [1, 2, 4, 13]). However, a thorough account of apraxia of speech would attempt to characterize a range of patterns in the breakdown of various articulatory spatiotemporal relations. While articulatory studies are rare in the literature on apraxia, those that exist have been valuable in illuminating certain deficits in temporal coordination [11 and references therein].

Figure 1: Articulatory movement tracking of the phrase "perfect memory" (provided thanks to L. Goldstein & C. Browman, after [3]).



The foundation of this research note is the belief that the availability of articulatory movement data will enable researchers to provide a fuller description of apraxia. Certainly, the meteoric rise in articulatory studies of non-disordered speech has been the primary impetus behind the recent evolution of sophisticated models of the phonetics-phonology interface. One means of acquiring articulatory data is by tracking the movement of transducers adhered to the articulators, such as with X-ray microbeam or magnetometry. In a now classic example from [3], Figure 1 shows articulatory movement tracking used to capture differences in temporal coordination in the consonant sequence in "perfect memory." When said carefully (top), this sequence is heard as [ktm]; however, when said casually (bottom) it is hear as [km]. The reason for this difference in the perceived consonants can easily be understood by looking at the pellet trajectories for the articulators: the /t/ is not present in the transcription of the casual token because temporal overlap among the consonants has increased such that the occlusion of the /t/ is "hidden" by the neighboring /k/ and /m/ closures. Importantly, even though it is not revealed by the acoustic record, there is clear articulatory evidence of the

Figure 2: The phrase "It's a musk ox" spoken by an unimpaired speaker.

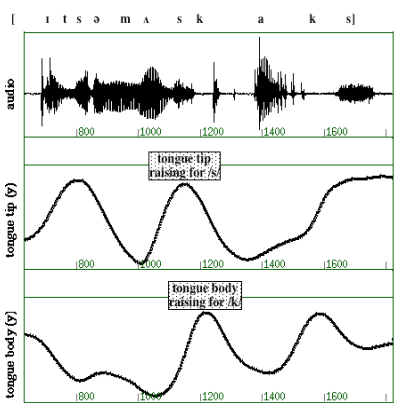
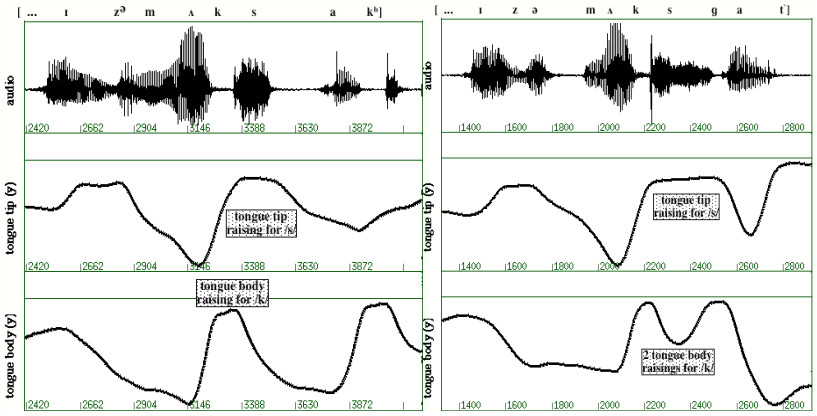


Figure 3: The phrase "It's a musk ox" spoken by HN [with apraxia]



presence of a gesture for /t/, not for its deletion. The acoustics are a result of the overall temporal patterning of all co-occurring gestures. In our following examination of apraxic speech, we will see several examples, like this one, where the articulatory record is more informative as to the execution of the speech gestures than the acoustic one.

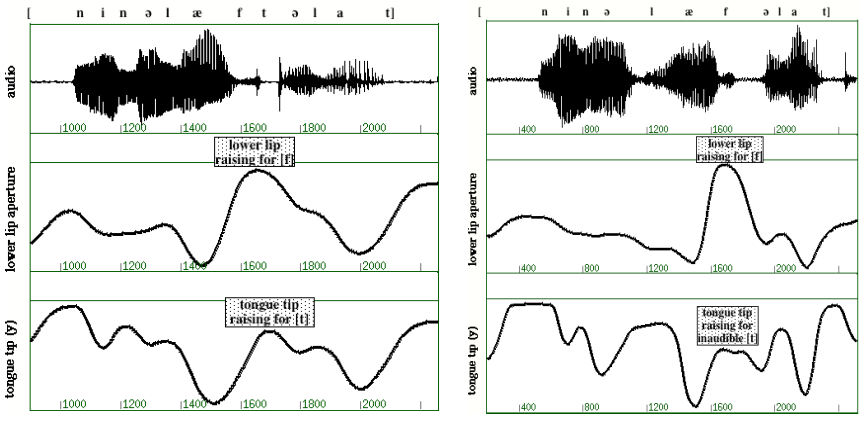
Below, we briefly present a selection of the types of errors that can be evidenced using a magnetometer [10] to study the speech of an individual with frontal left hemisphere damage. This is intended to demonstrate some advantages of direct kinematic observation in describing errors in apraxia of speech (AOS).

2. MOVEMENT TRACKING AND AOS

Subject HN was a participant in an experiment on the relations of articulation and agrammatism. He was recruited for this study based on an initial clinical diagnosis as nonfluent aphasic following the administration of the Boston Diagnostic Aphasia Examination.[1] In an MRI lesion study, there was no evidence of damage to the right hemisphere. In the left hemisphere the lesion was large and extended to both cortical and subcortical areas. As part of the larger experiment, HN was recorded using the magnetometer technique [10] to track the movement of his articulators during the production of sentences designed to investigate the coordination of consonant sequences at phrasal, morphological, and syllabic junctures. He was asked for 15 repetitions each of a series of six sentences, recorded with sentences blocked and each token preceded by a model prompted by the experimenter.[2] For purposes of qualitative reference only, the same corpus was collected for a talker without articulatory impairment. The movements of transducers adhered to the lips and tongue were recorded simultaneously with the audio signal.[3] Production errors involving each of the elicited consonant sequences—[sk], [ft], [kt]—are shown here.

Figure 3 shows two tokens of the same utterance as produced by HN, the apraxic speaker; an unimpaired production is shown in Figure 2 for reference. The transcription and audio record show a metathesis of the /s/ and /k/. In the articulatory record for token one [left] it is evident that the tongue body raising for [k] has occurred inappropriately early relative to the tongue tip raising for the [s]. In this case, the articulatory record is congruent with the audio record. However, the speaker produces a very different response to the same prompted utterance in the token shown next [right]. In this case, the tongue tip raising is substantially prolonged, and there are two tongue body raising gestures during consonant cluster interval. There is

Figure 4: The phrase "Nina laughed a lot". Left: token from an unimpaired speaker; Right: token from HN [with apraxia]. (The /f/ is represented by the vertical distance between the maxillary and lower lip receivers, oriented so that the highest position on the y/-axis represents minimum interreceiver distance).



no way to determine whether this error originated as an error in the production of the target [sk] cluster or whether it is, for example, an anticipatory error provoked by the [k] in the following word. Nevertheless, it is noteworthy that the word <musk> would likely be transcribed by a listener as [mʌks] in both tokens despite the very different articulatory events that occurred in creating this percept.

Figure 4 (left) is a production by the unimpaired speaker of an utterance containing the consonant cluster /ft/. Figure 4 (right) shows the same utterance produced by HN. However, in this case, while a tongue tip movement is apparent, the tongue tip was not raised high enough for a closure to be formed, and as a result, there is no /t/ in the acoustic or transcriptional record, *despite* the presence of tongue tip raising in the articulatory record. That is, the /t/ would be described as omitted or deleted if the acoustic record alone were available. Again, an interpretation of the source of this type of error is the kind of understanding that could be clarified with further experimentation involving the collection of movement tracking data. For example, the inadequate movement exhibited in Figure 4 (right) could be a consequence of the biomechanical coupling of the oral articulator with the mandible, as the jaw is moving upward for the production of the target consonant(s), rather than a consequence of independent movement of the articulator. Such coupling can only be evaluated with articulatory movement data.

Figure 5 is a different utterance also with an /ft/ target cluster. Here the tongue tip record shows no trace of a tongue tip gesture for /t/. As with the token shown in Figure 4, this too would be described as an omission error. Thus, errors isomorphically described in a transcriptional approach can have very different origins in the articulatory behavior of a speaker. This difference cannot be identified in a non-articulatory record.

Figure 6 presents a somewhat different kind of error in a /kt/ target cluster. Because the tongue tip gesture for what was a target /t/ is somewhat too long and small in magnitude, acoustic frication occurs and a "substitution" error is recorded in the transcriptional record, yielding /s/ in place of /t/. Given the temporal and spatial instabilities in apraxic speech, this type of error is expected to be common. In future work, it might prove possible to differentiate frank substitution errors from misarticulations and from well-formed productions through comparison of gestural kinematic characteristics.

Figure 7 shows a phenomenon similar to the intrusive velar gestures reported by [6]. In this token, the word-final [s] and the word-initial [k] are both present in the transcription and in the articulatory record. However, an unexpected tongue tip movement intrudes during the [k] closure. This movement goes unrecorded in the transcriptional record as it is obscured or "hidden" by the simultaneous velar closure, and, were we relying on the transcription alone, this production of [sk] would be considered fairly successful, though slow. When we examine the actual articulation of the speaker, however, the error is uncovered. Hardcastle points out [6] that the intrusion of a constriction may be considered an error of temporal coordination if it can be attributed to a phone intended to be in the target utterance but at another temporal location. This is a possible interpretation of the token shown in Figure 7, as a later [s] proves missing in the articulatory record.

3. DISCUSSION

The description of apraxia of speech as a disorder of movement coordination is amply justified. It is

Figure 5: The phrase "See the loft alone" spoken by HN [with apraxia]

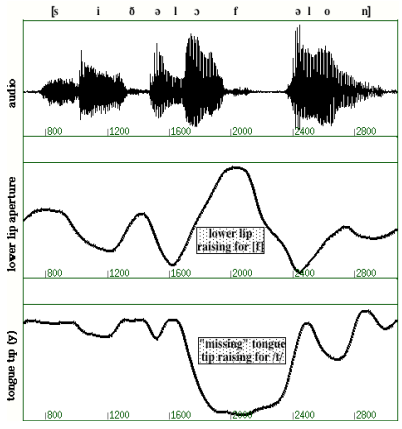


Figure 6: The phrase "See the fact alone" spoken by HN [with apraxia]

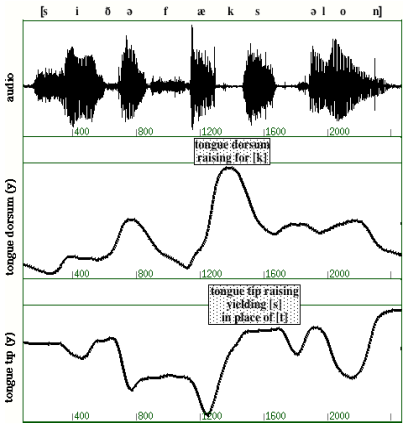
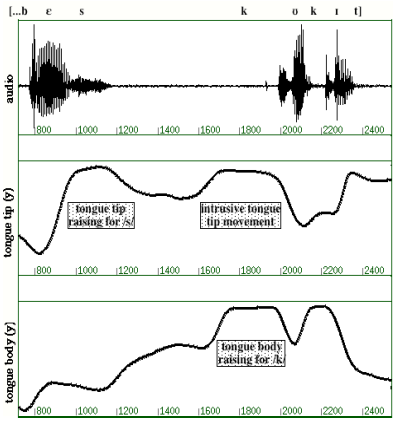


Figure 7: The phrase "Here Bess cooks it" spoken by HN [with apraxia]



important to recognize, however, that there is no single or simple signature of disordered motor control in aphasia. An understanding of the various phenomena that can occur in dysfluent speakers has in the past been sought using transcriptional and acoustic analyses. However, a severe limitation of transcription and acoustic analyses is that they cannot describe all important articulatory events. This point has been made for normal articulation [3]. The reason for this inadequacy is that the acoustic (and by extension, transcriptional) record results from many simultaneously occurring articulatory events. Due to the coproduction of speech movements, the acoustic record rarely stands in a one-to-one relationship with a single, clearly identifiable, articulatory event. As Hardcastle eloquently explains, an auditory evaluation of disordered speech may fail to illuminate "…the intricate events that take place during speech production, the complex overlapping movements of the articulators…and the transitional movements between target vocal configurations, although it is precisely these details of the dynamics of speech organs that may be crucial diagnostically. In fact, the use of discrete symbols in an auditory-based transcription may give quite a misleading impression as by its very nature it often forces the listener into making categorical decisions about speech sounds..." [6 p. 114-115; see also 12].

In the examples of apraxic speech that we have presented, we have seen productions that indicate that articulatory events may be unrepresented in the acoustic record or may be reflected in ways that fail to illuminate the articulatory basis of errors. For this reason, analysis of movement patterns can provide a more complete and accurate understanding of the disorder than can acoustic analysis alone. In recent years, techniques for visualizing lesions have become ever more accurate, and experiments on agrammatism have become increasingly linguistically sophisticated. However, advances in the exploration of apraxic symptoms have been largely neglected. We suggest that the collection and analysis of articulatory movement data is a promising area for advancement in the study of apraxia.

Acknowledgments

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[1] Because of the emphasis here on articulation, we will not discuss HN's agrammatism except to say that his ability to respond to a technique for eliciting subject and object relatives was quite limited [8, 9]. In another task, HN failed to produce the appropriate inflectional endings for verbs (third person present & past tense) for words in about 80% of cases. These results are roughly comparable with those of [5] in a similar experiment on subjects classified as having Broca's aphasia.

[2] Utterances from the subject with aphasia were accepted only if they contained an acoustic representative for each word in the target utterance. Other than implementing this criteria for token inclusion, the experimenters made no judgments about the perceptual deviance of the words.

[3] Small, pellet-shaped receivers were adhered in the midsagittal plane on the upper and lower lips and on the tongue tip, blade, body, and dorsum. Two receivers placed on the nose and the maxilla were used for the correction of head movement, and two receivers attached to a bite plate were used to record the subject's occlusal plane. Data were rotated to bring the occlusal plane into coincidence with the x-axis.