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Speech errors in progressive non-fluent aphasia

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ABSTRACT

The nature and frequency of speech production errors in neurodegenerative disease have not previously been precisely quantified. In the present study, 16 patients with a progressive form of non-fluent aphasia (PNFA) were asked to tell a story from a wordless children's picture book. Errors in production were classified as either phonemic, involving language-based deformations that nevertheless result in possible sequences of English speech segments; or phonetic, involving a motor planning deficit and resulting in non-English speech segments. The distribution of cortical atrophy as revealed by structural MRI scans was examined quantitatively in a subset of PNFA patients ($N = 7$). The few errors made by healthy seniors were only phonemic in type. PNFA patients made more than four times as many errors as controls. This included both phonemic and phonetic errors, with a preponderance of errors (82%) classified as phonemic. The majority of phonemic errors were substitutions that shared most distinctive features with the target phoneme. The systematic nature of these substitutions is not consistent with a motor planning deficit. Cortical atrophy was found in prefrontal regions bilaterally and peri-Sylvian regions of the left hemisphere. We conclude that the speech errors produced by PNFA patients are mainly errors at the phonemic level of language processing and are not caused by a motor planning impairment.

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1. Introduction

Errors in the production of the segments comprising speech are made by all speakers of a language. For healthy speakers, this happens infrequently and often to humorous effect, evoking reference to the Reverend William Spooner (1844–1930). A more severe impairment of the production of speech sounds is found in pathological conditions. Much of the literature on speech production errors in subjects with an acquired language impairment has focused on patients who have suffered a cerebral vascular accident (Canter, Trost, & Burns, 1985; Dronkers, 1996; Peach & Tonkovich, 2004; Romani, Olson, Semenza, & Grana, 2002). In the last quarter-century, a language disorder resulting from neurodegenerative disease has been described. This is differentiated from the post-stroke syndrome by its progressive nature and so termed "primary progressive aphasia." The term "progressive non-fluent aphasia" (PNFA) is now widely applied to a group of those patients whose speech is notably dysfluent (Gorno-Tempini et al., 2004; Grossman & Ash, 2004; Grossman, Mickanin, et al., 1996; Hodges & Patterson, 1996; Knibb, Woollams, Hodges, & Patterson, 2009; Snowden, Neary, & Mann, 1996; Thompson, Ballard, Tait, Weintraub, & Mesulam, 1997). This is often a variant of frontotemporal lobar degeneration in which one of the most salient features is effortful speech, with hesitations, retakes, pauses, and errors in the production of words. Patients with this syndrome also characteristically exhibit agrammatism and produce simplified grammatical forms (Ash et al., 2009). They are also impaired in the comprehension of complex syntax (Peelle et al., 2008). Executive resources are impaired as well, but comprehension of single words is relatively spared (Grossman & Ash, 2004; Grossman, Mickanin, et al., 1996; Libon, Massimo, et al., 2007; Libon, Xie, et al., 2007; Snowden et al., 1996).

Little attention has been devoted to the study of speech errors in neurodegenerative disease, even though detailed assessments of speech errors can be quite informative about the nature of the language system and its breakdown in conditions such as PNFA. Discussion of the errors in speech production made by patients with either brain lesions or neurodegenerative disease frequently assumes that the errors are caused by a motor planning impairment (Dronkers, 1996; Duffy, 2006; Gorno-Tempini et al., 2004; Josephs et al., 2006; Peach, 2004) known as apraxia of speech (AOS). The characteristics of AOS that are most often cited are groping towards the articulation of a word, distorted sounds, and dysprosody that often results in the production of a sound that is not part of the speaker's native language (Croot, 2002; McNeil, Robin, & Schmidt, 1997; Wertz, LaPointe, & Rosenbeck, 1984). While the immediate cause of a speech error must logically be that the speech articula-

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tors are not placed in the right place at the right time in the production of a given speech sound or word, the precipitating cause of the production error could occur at a level of implementation upstream from the activation of the articulators (Canter et al., 1985; Romani et al., 2002). A distinction thus is made between AOS and phonemic paraphasias (Canter et al., 1985; Peach & Tonkovich, 2004). Phonemic paraphasic errors are described as phonemes subjected to processes of substitution, deletion, addition (insertion), or transposition (metathesis). These errors are said to involve processes that are more central than activation of the articulators because the speech sounds which are produced are relatively undistorted, actual speech sounds; substitutions and exchanges of speech segments are typically related to the original (intended) speech segments; and misplacement in a word suggests that the error occurs at the level of abstract lexical representation, rather than the surface level of articulation. The present investigation examines the nature of speech errors made by patients with PNFA. We sought to determine whether deficits in speech production in this neurodegenerative disease primarily arise from impairments in the language system or impairments of the motor system.

In the characterization of speech errors it is important to distinguish between two levels: the abstract level of the system of speech sounds in a language and the concrete level of the physical realization of speech sounds. The more abstract level is phonemics, the units of which are *phonemes*. The phoneme /t/, for example, sounds different depending on its position in a word, as illustrated in Fig. 1A; but to the speaker, all the different variants of /t/ are in some sense the same, and the speaker may well not even realize that the /t/s in different positions sound different.

The physical features of the sound that is produced when a person speaks constitute a *phone*. The different variants of the abstract phoneme, realized as different phones, can be described in terms of their articulatory and acoustic properties, as is illustrated in Fig. 1B. Phonetics is the study of speech sounds at this level.

A phonemic error occurs when a person produces a sound that is a well-formed phoneme of the language but not one that was intended by the speaker or anticipated by the listener, as in Examples 1a and 1b:

1(a) They have a *smole* 'smile' (*smole* rhymes with *mole*).
1(b) . . . coming out of the *gar* 'jar' (*gar* rhymes with *bar*).

A phonetic error occurs when a speech sound is produced that results in a word which is not a possible sequence of sounds in the speech system of the speaker. This can result from a sound that does not occur in the speech system or from a combination of sounds that does not occur in the language. These productions could be due to an impairment of motor control, or, if produced consistently, they could be caused by an impairment of the mental representation of the phoneme. Examples 2a and 2b show the most frequent type of phonetic error, which results from the lenition of a consonant, that is, the softening of the articulatory force required to produce a well-formed phone. Since these sounds are not part of the inventory of English phonetics, there are no letters of the English alphabet to transcribe them; phonetic symbols borrowed from other alphabets are used. In both examples, the phonetic symbols represent voiced fricatives. The character Ð in (2a) is not a standard phonetic symbol, but it follows the convention of using barred symbols to represent fricatives (Pullum & Ladusaw, 1986). In this case, it transcribes a voiced alveolar slit fricative, in contrast to the voiced grooved fricative [z].

2(a) kiÐ 'kid'.
2(b) doγ 'dog'.

It is an empirical question whether the errors of PNFA patients are more often phonemic or phonetic. If the errors are predominantly phonemic, there might be an impairment of language that disturbs the retrieval of the correct phonemes, or there might be an impairment of the executive resources needed to retrieve the appropriate phonemes and assemble them into the correct sequence. If the errors occur at the level of phonetics, this may imply motor difficulty such as an impairment of motor planning. Groping may reflect feedback from an intact phonemic system attempting to guide the motor speech system to produce the correct phonetic segment. If the error occurs consistently, this could implicate either the mental representation of the phoneme itself or its manner of articulation.

In a study of single-word processing in two PNFA patients on tasks of naming, repetition, and reading, Croot et al. found better performance on tasks in which the stimulus provided information about the phonological output: both patients performed best on reading, less well on repetition, and least well on naming (Croot, Patterson, & Hodges, 1998). They propose that these patients have difficulty with phonological encoding, so when the task stimulus provides support for that encoding—as do printed or spoken stimuli—performance is improved. In contrast, a stimulus in the form of a picture of an object provides no clues to the phonological form of the target word, which results in the poorest performance among the tasks. These investigators did not distinguish between phonetic and phonemic errors in transcribing the subjects' speech, but they address the question of whether the impairment occurs at the level of phonological encoding or at the level of articulation, involving the movements and coordination of the tongue, lips, velum, and vocal folds. They acknowledge that the errors they recorded could have been caused by "phonetic disintegration," thus leaving open the question of whether the speech errors result from an impairment at the cognitive level or the motor level.

With the goal of illuminating the source of speech errors in PNFA, we undertook to classify speech errors as phonetic or phonemic and to characterize these errors in linguistic terms in order to understand the underlying process of deformation of the speech stream. Further, we examined the linguistic and non-linguistic correlates of speech errors as a means of assessing the neurological underpinnings of speech errors in PNFA.

A. Phonemics: The system of phonemes in a language

A phoneme is an abstract unit of speech which has psychological salience for the speaker

/t/: top, stop, pot, bottom

B. Phonetics: The study of the physical realization of speech sounds

A phone is the physical realization of a speech sound

aspirated:	top
unaspirated:	stop
aspirated or unreleased:	pot
unreleased or deleted:	postbox
flapped:	pot of gold, bottom

Fig. 1. Terminology.

2. Methods

2.1. Subjects

We studied 16 mildly to moderately impaired PNFA patients diagnosed by an experienced neurologist (MG) in the cognitive

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