When words don't come easily: A latent trait analysis of impaired speech motor planning in patients with apraxia of speech

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ABSTRACT

Apraxia of speech (AOS), a speech impairment caused by left hemisphere stroke, is considered as a clinical model to study the organization of speech motor plans. An earlier nonlinear gestural (NLG) model of word production based on AOS speech error data informs about the structure of phonetic plans of words (Ziegler & Aichert, 2015), but with the disadvantage that it does not allow for single case testing. The latent trait approach presented here complements this model by permitting assessment of the extent to which an individual non-standard word production pattern conforms to the NLG framework.

A Rasch model of speech planning ability was calculated using accuracy data from 2 examinations each of 33 clinical cases on 114 German words. Case fit parameters of the patient sample revealed high model conformity of all cases. In simulation studies, simulated cases with response patterns reflecting five different error mechanisms were examined: random, word frequency based, syllable number based, consonant number based, and NLG based. Inclusion of simulated cases in the Rasch model revealed that only the NLG simulation was compatible with the latent trait reflecting speech motor planning ability.

Our approach provides a powerful tool to test whether an observed pattern of sound production impairment conforms to the AOS pattern. Under the premise that AOS is considered as a clinical model of acquired speech planning abilities, this framework allows for the testing of specific hypotheses concerning the phonetic basis of ease-of-articulation.

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and eventually also the ventral portion of the left precentral motor strip and the left anterior insula (Ackermann, Hage, & Ziegler, 2014; Berken, Gracco, Chen, & Klein, 2016; Ziegler, Schöderle, Aichert, & Staiger, in press).

Lesions to these regions in the brain, mostly after infarctions of the left middle cerebral artery, often lead to a condition termed apraxia of speech (AOS). In severe cases or early after infarction, patients with AOS can be unable to speak (Ballard, Tourville, & Robin, 2014). At later stages in the course of recovery or in milder cases these patients present with a speech impairment characterized by dysfluent speaking with speech initiation problems and effortful articulatory groping, false starts and self-correcting restarts, and by frequent segmental and subsegmental errors involving distortions or substitutions of phonemes and distorted sound transitions (Ziegler, 2008). As an example, an apractic speaker attempting to pronounce the word \( /gi\acute{w}k/ \) may produce

\[
[d^\circ \ldots q]^{\prime}y{k}^\circ
\]

with a “false start” on an alveolar stop, a re-start after a pause filled by visible searching movements of the articulators, ephenthesis of a brief schwa-like vowel in the consonant cluster, and an alveolar release of the velar stop in the coda.

Visible and audible speech effort in these patients signals that speaking is no longer a “physiological pianissimo” (Lindblom, 1990) to them. AOS patients are clearly aware of their problem and often express their distress and resignation about the obvious loss of what has been so easy before the stroke: the capacity of co-ordinating the articulators for the production of speech (Ziegler, Aichert, & Staiger, 2012).

For this and for other reasons, apraxia of speech is considered as a model of how the acquired motor capability of speaking dissolves after lesions to the brain's network involved in speech motor planning. In this vein, the error patterns observed in AOS may evidence the sites of fracture within the architecture of speech motor plans: The more stably an articulation pattern is represented in the speaker's brain, as a result of practice-related neural plasticity, the less vulnerable will it be to apraxic impairment after a stroke. Conversely, the speech patterns that are more error prone in apraxia of speech are deemed represented by less resilient motor plans within the brain's speech motor network, as a consequence of their less frequent occurrence in the patient's native language.

Hence, a key question is: What is easy and what is hard to say for a patient with apraxia of speech?1 This question is difficult to answer because patients with AOS are rather inconsistent in their speech accuracy. Unlike patients whose speech organs are paretic or whose movements are akinetic (like in Parkinson's disease) or ataxic (like in disorders of the cerebellum), an apractic speaker may on one instant make an error on a word, and on a second instant produce the same word with surprising accuracy (Staiger, Finger-Berg, Aichert, & Ziegler, 2012). However, this is not to say that the patterns of apraxic speech errors are entirely random. Several factors are known to have an impact on speech accuracy in AOS patients, such as the length of a word in terms of syllable number or number of consonants, the complexity of the syllables in a word, or the frequency of occurrence of a word or a syllable in the patient's language (Aichert & Ziegler, 2004; Nickels & Howard, 2004; Staiger & Ziegler, 2008). Moreover, it has also been shown that metrical properties play a role, in the sense that metrical patterns that are frequent in a language, e.g., the trochee in German, are less vulnerable to AOS errors than infrequent patterns (Aichert, Späth, & Ziegler, 2016). Speech accuracy in apractic speakers varies stochastically as a function of these factors.

A major problem in separating the influences of these individual factors on apraxic speech accuracy derives from the fact that they mutually interact: At a given syllabic length, any increase in the number of phonemes will go hand in hand with an increase in the complexity of its syllables, and increasing syllable numbers create less complex syllables when phoneme numbers are kept constant.

For this reason including accuracy data from a large number of patients with AOS on a large number of words, the percentage of correct responses in the mentioned examples was 83% for /ha:kan/ (engl. hook), 55% for /gi\acute{w}k/, and 32% for /ju\acute{e}vel/. This makes it difficult to decide, for instance, whether and how words like /ha:kan/ (engl. hook), /gi\acute{w}k/ (engl. luck), and /ju\acute{e}vel/ (engl. jewel) differ in their articulatory demands, because they share the property of having three consonants, but differ in their syllabic lengths, their syllable complexity, and their metrical patterns.

Empirically, in a recent study including accuracy data from a large number of patients with AOS on a large number of words, the likelihood of accurate word production by apractic speakers is calculated stepwise following a word's gestural structure as exemplified in Fig. 1. Initially, each gesture is assigned a common base probability \( p \) of accurate gesture production. The likelihood that a combination of two gestures is produced accurately is then modelled through a weighting of their joint probabilities of accurate production by coefficients depending on their location within a syllable and within the metrical architecture of the word (Fig. 1). As an example, for a sequence of a consonant gesture \( c \) followed by a vowel gesture \( v \), the probability \( p(cv) \) of correct articulation of the \( cv \) sequence is

\[
p(cv) = p^2 \cdot c_{on},
\]

with \( c_{on} \) representing the degree of joint coordinative planning of the two gestures. Weighting coefficients \( >1 \) indicate deep

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1 The terms “easy” and “hard” are used here to characterise the motor proficiency requirements associated with the pronunciation of a given word. Ladefoged (1990) had criticised the term “articulatory ease” as “unscientific” because it is language-specific and cannot be measured. Here we evade Ladefoged's criticism by considering the easy/hard dimension only within the limits of a specific language (i.e., German) and propose an index to measure it as a latent trait (i.e., through speech error analyses in AOS). Note that the easy/hard dimension has also been used in other contexts, e.g., to describe the recognisability of words (e.g., Gahl, 2015).

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