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Interaction and representational integration: Evidence from speech errors

Matthew Goldrick *, H. Ross Baker, Amanda Murphy, Melissa Baese-Berk

Department of Linguistics, Northwestern University, 2016 Sheridan Rd., Evanston, IL 60208, USA

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ABSTRACT

We examine the mechanisms that support interaction between lexical, phonological and phonetic processes during language production. Studies of the phonetics of speech errors have provided evidence that partially activated lexical and phonological representations influence phonetic processing. We examine how these interactive effects are modulated by lexical frequency. Previous research has demonstrated that during lexical access, the processing of high frequency words is facilitated; in contrast, during phonetic encoding, the properties of low frequency words are enhanced. These contrasting effects provide the opportunity to distinguish two theoretical perspectives on how interaction between processing levels can be increased. A theory in which cascading activation is used to increase interaction predicts that the facilitation of high frequency words will enhance their influence on the phonetic properties of speech errors. Alternatively, if interaction is increased by integrating levels of representation, the phonetics of speech errors will reflect the retrieval of enhanced phonetic properties for low frequency words. Utilizing a novel statistical analysis method, we show that in experimentally induced speech errors low lexical frequency targets and outcomes exhibit enhanced phonetic processing. We sketch an interactive model of lexical, phonological and phonetic processing that accounts for the conflicting effects of lexical frequency on lexical access and phonetic processing.

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1. Introduction

Theories typically assume multiple independent stages of processing underlie the production of speech. In such theories, representations at each processing stage primarily reflect distinct dimensions of linguistic structure. Conceptual processes, representing the speaker's intended message (e.g., <furry><four-legged><feline>), drive the retrieval of a syntactically and semantically appropriate lexical representation (<CAT>) within lexical selection processes. Sound structure encoding processes retrieve/specify the phonological structure for this lexical item (e.g., /k/ /ae/ /t/); a detailed articulatory plan is then constructed and executed by phonetic processes (e.g., for /k/, forming a closure at the soft palate while abducting the vocal folds; Garrett, 1980, et seq.). Although many theories make similar assumptions regarding the distinction between various representational types and processes, they differ in how these processes interact with one another. Highly discrete theories (e.g., Garrett, 1980) rigidly enforce the separation of processing stages; furthermore, the representation of distinct aspects of linguistic structure is strictly segregated. A large body of work has shown that such systems cannot adequately account for data from reaction time and error patterns in neurologically intact and impaired monolingual speakers (for reviews, see Goldrick, 2006; Vigliocco & Hartsuiker, 2002) as well as multilingual speakers (for reviews, see Costa, La Heij, & Navarrete, 2006; Kroll, Bobb, & Wodniecka, 2006).

To account for these data, theories with greater degrees of interaction between speech production processes have been proposed. In the context of spreading activation theories, interaction has been increased by altering both the feed-forward and reciprocal, feed-back flow of activation between processing levels (see Rapp and Goldrick (2000),

* Corresponding author. Tel.: +1 847 491 8053; fax: +1 847 491 3770.
E-mail address: matt-goldrick@northwestern.edu (M. Goldrick).

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for discussion). One specific mechanism is cascading activation; this allows information at "early" processing levels to interact with later stages of production processing. For example, during lexical selection semantic associates of the target are active (e.g., during processing target <CAT>, <RAT> and <DOG> are partially activated). Cascading activation allows these non-target representations to activate their sound structure representations, producing priming of words phonologically related to semantic associates of the target (Costa, Caramazza, & Sebastián-Gallés, 2000; Peterson & Savoy, 1998), as well as a bias for mixed errors–errors overlapping on both phonological and semantic dimensions with the target (e.g., CAT → "rat;" Rapp & Goldrick, 2000).

An alternative means of increasing interaction is through integrating distinct dimensions of linguistic structure. Relative to a highly discrete account, the structure of processing representations can be enriched such that *multiple* dimensions of linguistic structure are represented within a single level of processing. For example, rather than assume a strict distinction between sound structure encoding and phonetic processes (operating over purely phonological vs. purely phonetic representations, respectively), exemplar-based models of speech production (e.g., Pierrehumbert, 2002) have proposed that lexical representations are directly associated with fine-grained phonetic detail. This can produce effects not predicted by highly discrete theories. For example, in such an architecture, the direct links between lexical and phonetic representations can allow sounds in words with many vs. few lexical neighbors to be associated with distinct phonetic properties—despite having similar phonological structure (Pierrehumbert, 2002).

In this work we examine more closely the contrast between these types of mechanisms in the context of interactions between lexical, phonological, and phonetic structure. Previous research has shown that partially activated phonological representations influence subsequent phonetic processing. For example, if the target word "cold" is mispronounced as "gold" (written "cold" → "gold") the partial activation of the target sound /k/ results in a phonetic "trace" of the properties of /k/ in the acoustic/articulatory realization of the /g/ outcome (e.g., errors have longer voice onset times relative to correct, intentional productions of /g/; Goldrick & Blumstein, 2006). Furthermore, because increased interaction allows lexical representations to influence the sound structure encoding processes, traces are sensitive to lexical properties. Previous studies have examined lexicality, finding that nonword error outcomes exhibit greater phonetic traces of target properties than word outcomes (Goldrick & Blumstein, 2006; McMillan, Corley, & Lickley, 2009). For example, there is a greater influence of the intended /k/ sound in the phonetic properties of /g/ in errors like "keff" → "geff" (nonword error outcome) relative to errors such as "kess" → "guess" (word error outcome).

This study extends this research in two ways. We examine the influence of a different lexical variable—lexical frequency—on phonetic traces. In addition to manipulating the properties of error outcomes, we also manipulate the lexical frequency of targets. Because previous research has shown that lexical frequency exerts contrasting effects on lexical access and phonetic processing, manipulating target and outcome frequency allows us to examine the contrasting predictions of two distinct theoretical perspectives on how interaction between levels of processing in language production can be increased.

During lexical selection and the encoding of sound structure, high lexical frequency facilitates target processing, as reflected in decreased reaction times and higher accuracy for high frequency words (see Kittredge, Dell, Verkuilen, and Schwartz (2008), for a recent review). In contrast, during phonetic processing, words with *low* lexical frequency are enhanced. Low frequency target words are produced with longer durations and more extreme articulatory/acoustic properties (see Bell, Brenier, Gregory, Girand, and Jurafsky (2009), for a recent review). These contrasting effects provide a unique window into the mechanisms underlying increased interaction in the language production system.

If interaction is increased solely through cascading activation, the facilitation of high frequency sound structure representations is predicted to carry over into phonetic processes. This will produce a greater phonetic trace of high frequency target words in speech errors. The complementary pattern will be observed for high frequency outcomes; facilitation of the phonetic properties of outcomes will reduce the influence of targets, resulting in smaller traces for high vs. low frequency outcomes.

Alternatively, if interaction is increased by integrating phonological and phonetic representations—by including within sound structure representations a specification of the range of phonetic variation associated with the target form—traces will instead favor low frequency words. Under this account, the encoding of the sound structure of low frequency words will include activation of a representation specifying a narrow range of phonetic variation. This will strongly indicate that target properties should be present—yielding larger traces for low frequency target words. The activation of similar representations for low frequency outcomes will reduce the phonetic traces of targets relative to high frequency outcomes.

Utilizing a novel statistical method to identify speech errors produced in tongue twisters, we replicate the well-documented influence of lexical frequency on error probability. Errors are less likely to occur on high vs. low frequency targets and more likely to result in high vs. low frequency outcomes. We simultaneously document a contrasting effect of lexical frequency on phonetic traces. Low frequency words exert a stronger influence on phonetic processing than high frequency words. Traces are larger for low frequency targets; the activation of the enhanced phonetic properties of low frequency outcomes results in a reduction of traces. We conclude by discussing how the contrasting effects of lexical frequency on lexical access and phonetic processing can be integrated into interactive processing theories of speech production.

1.1. The phonetics of speech errors

A number of studies utilizing both acoustic (Frisch & Wright, 2002; Goldrick & Blumstein, 2006) and articulatory

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