Encoding of distributional regularities independent of markedness:

Evidence from unimpaired speakers

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Abstract

Romani, Galuzzi, Guariglia, and Goslin (in press) used speech error data from individuals with acquired impairments to argue that independent from articulatory complexity, within-language distributional regularities influence the processing of sound structure in speech production. Converging evidence from unimpaired speakers is reviewed, focusing on speech errors in language production. Future research should examine how articulatory and frequency factors are integrated in language processing.

Keywords: Frequency, markedness, speech errors, implicit learning, phonotactics
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Evidence from unimpaired speakers

Romani, Galuzzi, Guariglia, and Goslin (in press) use data from persons with acquired impairments to argue for independent contributions of within-language distributional regularities (i.e., the frequency of segments) and markedness (intrinsic properties of speech sounds, related to articulatory complexity) to speech production. This paper reviews converging evidence from unimpaired individuals that bolsters the claim that within-language frequency, over and above markedness, makes an independent contribution to the processing of speech by adult speakers.

The key type of evidence I draw on are artificial grammar learning studies. In such experiments, the distribution of speech sound structures in the experimental environment is manipulated. We can then examine if participants have internalized these distributional regularities and use this information during speech sound processing. Critically, by experimentally manipulating frequency, we are able to de-confound the association between frequency and markedness (e.g., making an unmarked segment that is high frequency in typical language use outside of the experiment low frequency within the experiment, and vice versa). Furthermore, if performance is comparable across counterbalanced frequency manipulations (e.g., a segment is high frequency for one set of participants and low frequency for another set), we can infer that intrinsic properties of the manipulated sound structures do not drive performance.
Independent effects of distributional regularities on experimentally-induced speech errors

I focus on results from a paradigm that, like Romani et al. (in press), uses speech errors as a dependent measure. However, departing from Romani et al., in this paradigm the dependent measure is the distribution of error outcomes rather than the distribution of errors on contrasting targets. These studies do not examine whether errors are more likely to occur on low vs. high frequency sound structures, but whether errors are biased to result in the production of erroneous high vs. low frequency sound structures.

This speech error paradigm was first introduced by Dell, Reed, Adams, and Meyer (2000). The design capitalizes on regular patterns in the distribution of speech error outcomes observed across many different studies and different languages (see Goldrick, 2011, for a review). Contextual speech errors – where the erroneous sound occurs elsewhere in the target utterance – tend to preserve intended syllable position. For example, suppose “hymn to sing” is mispronounced as “hymn to hing” (example from Dell, 1990). The erroneous [h] appears in the unintended syllable (third instead of first in string), but in the intended syllable position (onset).

In both spontaneous and experimentally induced errors, these syllable-position preserving errors are more likely to occur than an error like “hymn to ming” (where the erroneous segment is not only in an unintended syllable but also an unintended syllable position). This tendency to preserve syllable position is massively strengthened when the distribution of a sound is restricted within a language. For example, it is highly unlikely to observe an error like “hymn to siH” because /h/ occurs at the onset of words in English (him) but never in coda (*mih).
Dell et al. examined whether a strengthening of the tendency to preserve syllable position could also be induced by manipulating the distribution of sounds within an experiment. English-speaking adult participants read aloud tongue twisters composed of nonsense words made up of English sounds. The distribution of some of the sounds in the tongue twisters was constrained (e.g., /g/ was confined to onset and /k/ to coda position, or vice versa in counterbalanced conditions) whereas other sounds remained unconstrained (/f/ and /s/ occurred equally often in both onset and coda). As in previous work, errors resulting in experimentally unconstrained sounds tended to respect syllable position (roughly 70% appeared in the intended syllable position). Interestingly, similar to naturally occurring errors on sounds like /h/, almost all errors resulting in experimentally-constrained sounds respected syllable position (95-98%). This suggested that participants had internalized the distributional regularities of sounds in the experiment. Critically, the same pattern was observed across counterbalancing conditions. For example, regardless of whether /g/ was constrained to onset (word-initial) or coda (word-final) position, /g/ error outcomes almost exclusively respected syllable position. This suggests that even though the word-final voiced allophone of /g/ presents articulatory challenges relative to the voiceless unaspirated word-initial allophone of /g/ (Westbury & Keating, 1986), the production system is able to adapt—favoring production of a relatively articulatorily difficult sound structure. Note as well that in other experiments /g/ and /k/ were unconstrained while /f/ and /s/ was constrained. The pattern of performance on each segment reversed; now, /g/ and /k/ error outcomes preserved syllable position at a lower rate, while /f/ and /s/ error outcomes virtually always respected syllable position. While far from an exhaustive sampling of English sound structure, these manipulations suggest that the
production system can adapt to new distributions of English sounds even if those distributions favor articulatorily complex sound structures.

Dell et al. (2000) focused on categorical restrictions on speech sounds (/f/ always occurs in onset, never in coda). This contrasts with the patterns examined by Romani et al. (in press), who focus on graded distributions within a language (i.e., relative frequency of different speech sounds). Goldrick and Larson (2008) found that similar graded patterns could be acquired in the Dell et al. paradigm. Participants were exposed to probabilistic constraints associating segments to syllable positions to varying degrees. The results showed that as the probability of a segment occurring in a syllable position increased, the proportion of error outcomes that occurred in that position increased as well – suggesting participants can acquire graded as well as categorical distributions of speech sounds.

Additional results suggest that these speech error patterns arise in the same processes that give rise to phonotactic effects outside of the experimental context. In this paradigm, participants acquire durable, implicit, linguistically structured knowledge about the distribution of speech sounds. Evidence of durability of these constraints comes from studies showing retention up to one week after exposure. When adult participants are exposed to more complex phonotactic constraints (e.g., /f/ occurs in onset if the vowel is /ɪ/, but in coda if the vowel is /ɛ/), the distribution of their speech errors is not affected until the second day of testing (Dell et al., 2000; Warker & Dell, 2006; but see Smalle, Muylle, Szmalec, & Duyck, 2017, for earlier learning in preadolescent children). The emergence of such effects in adults appears

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1 One exception was when /s/ was intended to be in onset position; on these trials, no /s/ error outcomes were observed in coda. It’s possible this could reflect a secondary influence of articulatory/acoustic complexity on errors (Goldrick & Larson, 2010)
to be dependent on sleep (Gaskell et al., 2014) although amount of exposure may also contribute (Warker, 2013). Critically, once participants have acquired these complex constraints, they retain them over long periods. Warker (2013) had participants repeat tongue twisters for 3 days, finding that complex constraints impacted speech error distributions on days 2 and 3. When participants were brought back to the lab a week later, they showed the effect immediately on day 1. They did not have to re-learn the constraint in spite of receiving many contradictory examples from English in the intervening time—showing that they had retained novel constraints specific to the experimental setting.

Other results suggest this durable knowledge is similar to our knowledge of naturally occurring phonotactic constraints. Speech error patterns reflect implicit knowledge; debriefing shows little or no awareness of the phonotactic constraints, and results are not affected by explicitly informing participants of the constraints (Dell et al., 2000; Warker & Dell, 2006). Participants’ knowledge is generalizable; Warker and Dell (2015) found comparable effects of phonotactics for errors producing syllables that were present vs. absent from the set of tongue twisters. This knowledge is also sensitive to linguistic structure; Goldrick (2004) found that participants could acquire phonotactic constraints at the level of segments (e.g., /f/ is restricted to onset) as well as features (labiodental fricatives /f/ and /v/ occur in onset 75% of the time vs. 25% coda).

In sum, in Dell et al.’s (2000) paradigm participants implicitly acquire durable, linguistically structured knowledge of the categorical and gradient distributional regularities of the experimental environment – regardless of whether these distributional regularities favor or disfavor articulatorily complex structures. This suggests that sound structure processing in
production is influenced by distributional regularities independent of effects of articulatory complexity.

**Independent effects of distributional regularities beyond speech production**

I have focused on the Dell et al. (2000) paradigm as it connects with the dependent measure (speech errors) and cognitive processes (speech production) studied by Romani et al. (in press). However, these issues have been examined in other empirical domains. The logic of this work is similar to the studies discussed above. If participants can acquire experiment-specific distributional regularities regardless of whether this information favors or disfavors acoustic/articulatory complex patterns, it supports the independent encoding of distributional regularities within the language processing system.

For example, Seidl and Buckley (2005) assessed 9 month old infants’ sensitivity to phonotactic patterns of varying articulatory complexity. Infants were familiarized with a set of novel word strings that exemplified a particular phonotactic constraint (e.g., fricatives but not stops can occur in between two vowels). The degree to which the infants preferred a set of novel nonwords which either respected or violated this phonotactic constraint was assessed using the headturn preference procedure. Infants successfully acquired the phonotactic constraint; they discriminated the two types of nonwords, showing a novelty preference (preferring to listen to nonwords that violated vs. respected the constraint). Critically, infants exposed to articulatorily complex patterns (e.g., stops but not fricatives can occur in between two vowels) showed the same degree of learning as infants exposed to less complex patterns. This suggests infants can independently encode distributional regularities, unconstrained by markedness.
A wide array of such infant studies, along with findings from adult participants in speech perception, production, and metalinguistic tasks are comprehensively reviewed by Moreton and Pater (2012 a, b). Under many conditions, participants appear to be able to acquire distributional regularities with no sensitivity to the articulatory or perceptual complexity of the pattern (Moreton & Pater, 2012b). This is not simply because our behavioral measures do not have the statistical power to detect differences between phonotactic patterns. Many studies show substantial and reliable effects of formal structure (the complexity of the information needed to specify the pattern; Moreton & Pater, 2012a). An example of this type of effect was discussed above; acquiring complex phonotactic constraints in the Dell et al. (2000) paradigm requires additional training, including sleep (Gaskell et al., 2014; Warker & Dell, 2006). The reliable findings of difficulties with formal complexity show that these experimental paradigms do indeed have the statistical power required to detect differences between phonotactic patterns. This suggests that the failure to observe reliable effects of articulatory complexity are not false negatives, but rather reveal the production system’s ability to adapt to distributional regularities regardless of the articulatory complexity of the pattern.

Future directions:

Integrating distributional regularities and markedness

While this discussion has focused on the independent effects of distributional regularities on processing, it is important to keep in mind that articulatory complexity plays a key role in speech production (as Romani et al.’s (in press) data demonstrate). Following Romani et al., it is clear that we should not view markedness and distributional regularities as conflicting or competing accounts; rather, each type of structure makes separate, independent
contributions to the linguistic system. The challenge is specifying how each comes to make independent contributions and how they interact with one another to shape the differential acquisition, processing, and loss of speech sounds.

One possibility is that distributional regularities and markedness are encoded in separate (but perhaps interacting) stages of speech planning. Many psycholinguistic theories of speech production have proposed that lexical and morphological representations retrieve relatively abstract specifications of sound structure during planning processes. These then serve as input to subsequent speech motor processes that specify the precise trajectory of movements needed to produce speech sounds (see Goldrick, 2014, for a recent review). As planning representations and processes operate over relatively abstract representations, this framework does not require that planning processes be sensitive to articulatory complexity. This allows for an independent encoding of distributional regularities (during planning) and articulatory complexity (within speech motor processes).

Note that within this perspective both stages of processing are obligatorily engaged during speech production. This account therefore predicts that distributional regularities and articulatory complexity should always exert influences on speech production. Why then are articulatory complexity effects absent in so many of the studies of production in neurologically intact individuals? One possibility is that it reflects the restriction of stimuli in experiments to sound structures found in the native language of participants (particularly in the paradigm developed by Dell et al., 2000). The articulatory routines of these sounds may be so well-established that performance may be at ceiling. Planning processes can then be rapidly adjusted to encode new distributional regularities without leading to the emergence of
articulatory complexity effects (see German, Carlson, & Pierrehumbert, 2013, for one such model, where rapid adaptation to a novel accent is driven by adjustments to abstract, categorical representations).

This approach suggests that examination of the production of non-native sound sequences may provide insight into how more principles of more abstract phonological processes interact with articulatory complexity during speech. Some initial investigations of production of these sequences have been conducted in the context of the Dell et al. (2000) paradigm. Whalen and Dell (2006) gave participants some practice producing /ŋ/ in onset position and then asked the participants to produce tongue twisters where /ŋ/ was confined to this position. Fifty percent of the errors resulting in /ŋ/ outcomes occurred in onset. While this is lower than the syllable rate preservation observed in previous studies of experiment-specific phonotactic constraints that are more (not less) restrictive distributions of English sounds (e.g., /g/ confined to onset), it is striking that participants were able to (partially) override this language-general constraint in the context of the experiment. The intermediate performance observed may provide some insight into how different levels of processing overlap. It could be understood as a rapid adaptation during planning (confining an abstract representation of /ŋ/ to onset) combined with complexity effects in motoric processing (pushing /ŋ/ outcomes to coda). A similar pattern is found in an explicit training paradigm used by German et al. (2013); they find partially successful learning of a novel accent in which flaps (alophones of /t/ occurring intervocalically in words like butter) are produced in onset. More extensive investigation with a wider array of non-native structures (e.g., non-native clusters: Davidson, 2010; Karlinsky, 2013) accompanied by instrumental (acoustic/articulatory) analyses should
provide greater data on how these two aspects of complexity interact in unimpaired individuals.

Another avenue for empirical investigation could be bilingual individuals, who show increased difficulties during speech sound processing relative to monolingual speakers (e.g., increased rates of errors in tongue twisters composed of nonsense words: Gollan & Goldrick, 2012; Li, Goldrick, & Gollan, 2017). The increased error rates of bilingual speakers will, at the very least, pull performance off of ceiling; the increased variance in accuracy measures will provide for greater power to investigate difficulties in both planning and motoric processes.

Conclusions

Evidence from speakers without production impairments supports Romani et al.’s (in press) conclusion that distributional regularities make an independent contribution to speech production. Having eliminated two extreme hypotheses (either distributional or markedness information alone determines the nature of errors in speech production), the challenge is to navigate the more nuanced space of intermediate hypotheses incorporating both factors.
References


