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Learning to speak by listening: Transfer of phonotactics from perception to production

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ABSTRACT

The language production and perception systems rapidly learn novel phonotactic constraints. In production, for example, producing syllables in which /f/ is restricted to onset position (e.g. as /h/ is in English) causes one's speech errors to mirror that restriction. We asked whether or not perceptual experience of a novel phonotactic distribution transfers to production. In three experiments, participants alternated hearing and producing strings of syllables. In the *same* condition, the production and perception trials followed identical phonotactics (e.g. /f/ is onset). In the *opposite* condition, they followed reverse constraints (e.g. /f/ is onset for production, but /f/ is coda for perception). The tendency for speech errors to follow the production constraint was diluted when the opposite pattern was present on perception trials, thus demonstrating transfer of learning from perception to production. Transfer only occurred for perceptual tasks that may involve internal production, including an error monitoring task, which we argue engages production via prediction.

Introduction

Speakers learn to speak by listening. But how do acts of speech perception lead to change within the production system? Our ability to speak depends on the acquisition of general patterns such as the fact that, in English, adjectives precede nouns or that one says "an" before words beginning with vowels. This paper is concerned with perception-to-production transfer of a specific kind of generalization, *phonotactic constraints*. Phonotactics are constraints about the ordering of segments, typically within syllables. They are language specific and hence must be learned. For example, in English, /h/ must be a syllable onset (occur at the beginning of a syllable, e.g. /hum/) and /ng/ must be a syllable coda (occur at the end of a syllable, e.g. /song/). In Persian, though, /h/ can be a coda (e.g. /dah/ "ten"), and in Vietnamese, /ng/ can be an onset (e.g. /ngei/ "day").

Knowledge of native-language phonotactics emerges in infancy (e.g. Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993) and, throughout life, constrains language perception and production (e.g. Pitt, 1998). Production models assume that phonotactic constraints are consulted during the encoding of word forms, particularly during the construction of syllables (e.g. Levelt, Roelofs, & Meyer, 1999). Evidence for this assumption comes from speech errors. Just as Freud famously hypothesized that speech errors reveal unconscious wishes, modern psycholinguistics proposes that slips reflect the speaker's implicit linguistic knowledge, including phonotactics. Specifically, slips exhibit the *phonotactic regularity effect*. "Nun" might slip to the phonotactically *legal* syllable "nung", but not to the *illegal* "ngun" (Fromkin, 1971). Although the phonotactic regularity effect is not without exceptions, particularly when one examines the phonetic and articulatory

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details of slips (e.g. Goldstein, Pouplier, Chen, Saltzman, & Byrd, 2007), it is generally accepted that slip outcomes are strongly shaped by linguistic factors (see Frisch & Wright, 2002; Goldrick & Blumstein, 2006).

How does the production system acquire and modify its phonotactic knowledge in adulthood? Several studies have used a laboratory analogue to the phonotactic regularity effect to investigate the learning of phonotactic distributions (Dell, Reed, Adams, & Meyer, 2000). Participants recite strings of syllables that, unbeknownst to them, follow novel phonotactic constraints. For example, whenever a syllable contains the consonant /f/, it appears only in onset position. Although /f/ may occur in onset position in English, the absence of /f/ in a coda position is novel in that it represents a change in the phonotactics of everyday English. The learning of the novel constraint is revealed in the participant's slips. When some other consonant is mispronounced as /f/, the slip occurs in onset, rather than coda, position 95–98% of the time. It is as if the errors "know" that /f/'s must be onsets. Another way to say this is that the slips are 95–98% "legal" (5–2% "illegal") with respect to the experimental constraints, just as natural slips are legal with respect to language-wide phonotactics. Research using this speech-error paradigm has demonstrated that slips reflect the novel, experiment-specific constraints within minutes (e.g. Goldrick, 2004), sometimes in as few as 9 speaking trials (Taylor & Houghton, 2005). The strength of this influence depends on the frequency with which the constraints are experienced in production. That is, the strength of the tendency for slips of, say, /f/ to stick to, say, onset position, depends on the relative proportion of onset and coda /f/'s in the experiment (Goldrick & Larson, 2008).

We interpret the sensitivity of slips to the experimentally experienced phonotactic distributions as "learning" in the sense that it is change as a function of experience. Often, though, theorists distinguish between very temporary changes, referred to as "priming," and longer-lasting effects that constitute true learning (e.g. Taylor & Houghton, 2005). For example, Bock and Griffin (2000) asked whether structural priming in language production is the result of learning or priming. Priming was assumed to be caused by the normal persistence of activation that occurs in the performance of a task, here language production. They estimated that the decay of activation during production was on the order of a few seconds and hence that structural priming, which persisted in their experiment for 10 min, was a learning effect. Some effects of altered phonotactics on slips have been demonstrated to persist for 7 days (Warker, 2013). Warker and Dell (2006) introduced a computational model of how changes in phonotactic distributions affect speech errors and attributed the effects to alterations in the weights of connections in a network, as opposed to persisting activation. Attributing the effects to weight changes means that the network retains the changes unless further learning degrades them. However, our manipulations do not include demonstrations of the persistence of phonotactic learning, and so when we speak of learning, we simply mean change as a result of experience, without a further commitment to whether this is best described as priming or learning.

Like the production system, the perceptual system can also learn phonotactic distributions from brief experience. Onishi, Chambers, and Fisher (2002) presented adults with syllables that followed artificial constraints, and found that participants then processed "legal" syllables more quickly than "illegal" ones, thus demonstrating perceptual phonotactic learning (see also Bernard, 2015; Chambers, Onishi, & Fisher, 2010, 2011). But can a phonotactic generalization acquired from perceptual experience be transferred to the production system? We know that a single phonological form is easily transferred from perception to production through imitation. If we hear, but do not say, syllables in which /f/ is always an onset, will our speech errors obey that constraint?

Transfer of phonotactics from perception to production was sought in a study by Warker, Xu, Dell, and Fisher (2009). Participants did the speech error task used by Dell et al. (2000) in pairs, taking turns producing or hearing their partner produce sequences such as "hes feng neg kem". For half of the pairs, the produced and the perceived sequences followed the **same** constraint, such as */f/ is an onset and /s/ is a coda* (which we abbreviate as the **fes** constraint). For the other pairs, the produced and perceived sequences followed **opposite** constraints. For example, one person's sequences would follow the **fes** constraint, while the other person's sequences would follow the opposite **sef** constraint. If there is transfer of the perceived constraint to the production system, slips of participants in the same condition should adhere to the constraint present in production trials (since participants experience the same constraint in perception). It is the opposite condition that provides the critical test of transfer from perception to production: If heard syllables immediately impact production, oppositely distributed restricted consonants in perception should reduce the legality effect in production. That is, slips of participants in the opposite condition will not adhere as strongly to the production constraints, because the constraint experienced on perception trials will dilute the constraint present in production trials. If each heard syllable is as powerful as a spoken one, the legality of the restricted consonant slips in the opposite condition should be as low as that of unrestricted consonant (e.g. /n/, /g/, /k/, and /m/) slips. Slips of consonants that are not restricted to onset or coda are "legal" around 75% of the time – that is, they retain their syllable position around 75% of the time when they slip (Boomer & Laver, 1968).

Warker et al. (2009) found that in the same condition, as expected, the slips strongly adhered to the constraint present in the spoken sequences, with slips of /f/ and /s/ slipping to their "legal" positions between 94% and 100% of the time. However, there was no transfer at all in two experiments: restricted consonant slips of participants in the opposite condition looked very much like slips of participants in the same condition, almost always slipping to the positions that were "legal" in production. In a third experiment, there was robust transfer: in the opposite condition, the slips of experimentally restricted consonants were significantly less likely to adhere to the production constraints, compared to the same condition. The inconsistency in transfer across experiments was likely due to the task assigned during perception trials. For the two studies