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Commentary

The many facets of speech production and its complex effects on phonological processing

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In our commentary, we discuss two additional points about developmental speech production. First, we suggest that more precision is needed to accurately describe 'speech production' processes, and we suggest that hierarchical constructs from the adult literatures on articulatory phonology and speech motor control may be applicable to infants as well. Second, we discuss the implications from data that indicate that the effects of production are subject to task-, attentional-, linguistic-, and experience-related demands.

Vihman (2017) provides a novel perspective on phonological and lexical development, bringing together the fields of infant speech perception and early word production. In her article, she draws from a variety of fields – including attention and memory, face discrimination, self-action, and motor development – which highlights the complexity of language learning, a task where multiple sources of information need to be integrated during development. She argues that infants do not simply learn how to perceive isolated speech sounds before producing words, but rather, that these two processes occur concomitantly. There is increasing agreement that the development of speech perception and production are highly interrelated, and characterized by both implicit and explicit learning processes, and affected also by physiological maturation. Here we clarify and discuss two further points about this view. First, we suggest that more precision is needed to accurately describe 'speech production' processes, and then suggest that hierarchical constructs from the literatures on adult articulatory phonology and speech motor control may be applicable to infants. Second, we discuss the effects of production on language learning, arguing that production does not always aid learning and is subject to a number of task-, attentional-, linguistic-, and experience-related effects.

What is 'speech production?'

A variety of distinct vocal gestures are studied in the target article (e.g., babbling, vocal motor schemes [VMS], first words), and while all of these gestures fall under the umbrella of *speech production*, there is no clear evidence of a unitary relation between these behaviours and phonological processing. Future research might bring greater precision to

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the concept of speech production, and we suggest two ideas from speech motor control that will help future scholars do so. One idea is that the study of *physical* changes in the structure of the developing vocal tract is important. For example, previous work has modelled the physical growth of the infant vocal tract and made specific predictions about physical constraints on possible sensorimotor targets (e.g., Ménard, Schwartz, & Boë, 2004), predicting asymmetrical processing of low front vowels – physically easier to produce in infancy – versus high back vowels.

A second idea comes from work studying how the vocal tract is controlled by the human motor system to produce speech (e.g., Gracco, 1994). The general consensus in that literature is that speech motor control is hierarchically organized at multiple levels in adults: The specific movement trajectories of the speech effectors when executing a movement ('articulator-level' information) can be separated from the overall goal of the gestural movement ('task-level' information). While it remains unclear to what degree infants' motor systems are similarly organized, previous developmental studies have found that speech processing can be influenced by motor movements that do not share the same gestural task as speech (chewing), but do involve similar articulatory movements (/i/-like lip-spreading, Yeung & Werker, 2013). Future work must further consider how hierarchical speech motor control develops in early development.

The consistency of production effects

Even if we limited our discussion to only highly developed, referential speech gestures in older children, the overall picture is still far from simple. Producing speech has been shown to be beneficial for later recall and recognition in both adults (Zamuner, Morin-Lessard, Strahm, & Page, 2016) and children (Icht & Mama, 2015), but this production effect can be attenuated, or even reversed, due to task-, attentional-, linguistic-, and experience-related factors. In the adult literature, for example, speech learning is disrupted when engaging the speech production system in an unrelated task (Baese-Berk & Samuel, 2016). Varying effects of production are also seen in development. While children show better recall for words produced versus heard silently during training (Icht & Mama, 2015), the reverse effect is found with non-word stimuli, which likely increases the task complexity relative to words (Zamuner, Morin-Lessard, Strahm, & Page, 2015). An additional factor when considering young children's speech is the mismatch between the target and the output, which may cause further disruption in learning.

How might these seemingly contradictory results be resolved? Reversal effects are perhaps not unexpected, given the novelty–familiarity effect in Vihman's work, where infants show a novelty listening preference for VMS outside of their production repertoire, but a familiarity preference in their speech for VMS inside their production repertoire. Together, these findings suggest that learners may need a certain amount of perceptual experience before there is a beneficial effect seen in production. Nevertheless, this then raises the question of how much experience is necessary and whether this is an active process: Is there evidence for pre-selection?

Future answers to the nature of the production effect may be found in neuroimaging work, as hypothesized by McAllister Byun's and Tessier's (2016) analysis of neurobiological *dual-route* models of speech processing (Hickok & Poeppel, 2004). For example, in a task where young children hear speech strings that are not yet well practised in production, there should be more activation of the dorsal pathway, as the incoming

auditory signal will not yet have firmly established links to corresponding motor commands. However, if the speech stream contains sounds that young children have previously produced or acquired in production, links between the incoming auditory signal and motor commands would already be established, and the processing of the auditory signal would reflect a more advanced stage of processing, perhaps engaging higher-level encoding of the auditory signal (McAllister Byun & Tessier, 2016). While such models are speculative, future work along these lines may help us understand why production sometimes facilitates, and sometimes impairs phonological processing.

Conclusions

In order to more accurately describe early speech production and its effects on phonological processing in early development, we must take a closer look not only at the physical changes undergone over the first years of life, but also at motor parameters of speech production on multiple levels. Moreover, some research shows that the benefits of production on perception are not systematic: depending on various factors, production effects can be interrupted, and even reversed, if speakers (both children and adults) do not benefit from enough prior perceptual experience.

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