Interacting processes and developmental biases allow learners to crack the "what" code and the "who" code in spoken language

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Few would challenge the claim that the development of speech perception is shaped by the perceiver's active search for meaning. In the target paper, Janet Werker focuses on research from her lab and others on early word learning and argues that there is a bidirectional relationship between processing of referential meaning and speech perception such that each influences the development of the other. There is already strong evidence that there is an ongoing interplay between meaning and phonological processing in later stages of language acquisition that brings increasing sophistication on both sides of the arrow. This is perhaps most apparent when we consider real contexts that involve communicating about actions and events, not just concrete objects, which has been the focus of much of the early word-learning research. Take the following (true story) example. Two sisters (ages 8 and 5 years) are sitting at the dinner table arguing about who is smarter. The older one says: "*You're not smart; you can't even spell milk*." The younger one replies "*Yes I can*" and proceeds to knock over her glass of milk to show that she can "spill milk." Based on the current literature, we would not conclude that the 5-year-old in this story (if she is developmentally on track) is unable to distinguish the native vowels /I/ and/ɛ/. This example highlights that functional speech processing is a sophisticated categorization skill that requires knowing exactly when to attend to and when to ignore perceptible phonetic differences. As well, accurate speech categorization may be especially challenging when the critical segment is vocalic and thus involves a high level of easy-to-perceive signal variation across talkers and phonological contexts. The younger sister in our example ignored the small vowel quality variation in her sister's speech, not because she cannot discriminate the target vowels or is unfamiliar with her sister's speech or dialect, but because she does not have a meaningful lexical entry for "spell." Is her immaturity conceptual or perceptual? The capacities appear to be tightly intertwined. Consistent with this, studies on second language (L2) acquisition in adults show that their vowel perception in the L2 is correlated with their L2 vocabulary size (e.g., Bundgaard-Nielsen, Best, & Tyler, 2011a, 2011b).

The new twist that Werker is adding to this story is that the bidirectional interplay between referential meaning and speech perception does not emerge at some point in development, but is a key feature of the language acquisition process from its onset. This would explain recent findings indicating that infants are recognizing some words earlier in development than estimated based on prior research (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999, 2012) and that they are beginning to recognize words at the same time that they are beginning to fine-tune their perception to align with native language phonological categories (e.g., Kuhl, 1991; Polka & Werker, 1994; Werker & Tees, 1984). This, and other findings, support the idea that infants use their emerging ability to recognize distinct objects and people to bolster their speech perception and vice versa.

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Therefore, if meaning and speech perception develop in tandem and each drives the other, one could ask, then, what are infants doing in the months before they begin to recognize what a talker is referring to or labeling? The literature suggests that young infants are busy unpacking the social side of the speech code. Infants successfully extract information about who is talking early in development (the "who" side of the message), well before they begin to sort out the "what" side of the message, that is, the referential content of words. For example, at birth, infants recognize their mother's voice (Mehler, Beertoncini, Barriére, & Jassik-Gerschenfeld, 1978) and the rhythm of their native language (Mehler et al., 1988; Nazzi, Bertoncini, & Mehler, 1998). Moreover, infants recognize talker differences in their native language but not in a nonnative language (Johnson, Westrek, Nazzi, & Cutler, 2011) at 6 months, well before they possess an extensive lexicon. This early focus on the "who" side is also found in adults exposed to an L2, who improve their talker recognition skills in that L2 before they can comprehend fluent speech (Orena, Theodore, & Polka, 2015).

Once infants start tackling the linguistic "what" side of the code around 6 months of age, changes are found in their speech perception abilities. For example, studies on word segmentation show decreasing effects of a voice change when recognizing new words between 7 and 10 months (Houston & Jusczyk, 2000). More important for our current argument, a recent line of studies shows that while infants have an initial vowel bias in their early ("who"–driven) speech processing (Benavides-Varela, Hochmann, Macagno, Nespor, & Mehler, 2012; Bouchon, Floccia, Fux, Adda-Decker, & Nazzi, 2015), they develop at around 8 months, when appropriate for their native language, a consonant bias when they begin to focus on lexically driven "what" speech processing (Hochmann, Benavides-Varela, Nespor, & Mehler, 2011; Nazzi, 2005; Nishibayashi & Nazzi, 2016; Poltrock & Nazzi, 2015; for a review, see Nazzi, Poltrock, & von Holzen, 2016). This consonant bias becomes such a key feature of lexical processing that by 20 months of age, it is found to be position independent. In consonant–vowel–consonant (CVC) words, French-learning infants give more weight to both the onset and the coda consonants compared to the vowel (Nazzi & Bertoncini, 2009). Moreover, in VC.CV words, (Canadian) French-learning infants give more weight to the coda consonant of the initial syllable than to its onset vowel, even though it has the advantage of being in word-initial position (Nazzi & Polka, 2018).

These biases exploit the division of labor found in many languages with respect to the vowels and consonants and their role in supporting speech processing (Nespor, Peña, & Mehler, 2003). While both vowels and consonants play a multitasking role in supporting speech communication, they tend to share the workload in different ways. Vowels appear to have more weight than consonants with respect to indexical information (although, through prosodic marking, vowels also contribute important lexical and syntactic information). Consonants appear to be given more weight when processing lexical units. Hence, in many languages, infants would be expected to shift their initial vocalic processing bias to give more weight to consonants when starting to learn a lexicon. This in turn may impact how they process and pay attention to vocalic information, a challenging task as giving more weight to consonants at the lexical level does not

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mean that vowels do not play a role in distinguishing lexical entries. This adds some complexity to the developmental link between the processing of different linguistic levels invoked by Werker, given that it appears that the emerging lexicon is not going to impact the different aspects of phonological processing, namely, the processing of consonants versus vowels, in the same way.

One issue that has not yet been directly explored is whether these phonological biases in processing can be modulated by context, hence by the type of processing infants engage in a given task. Would infants, after having developed a consonant bias in lexical processing, modulate their bias depending on whether they face a task that motivates them to prioritize the "who" message versus the "what" message? For example, would the familiarity of the voice they hear impact these phonological biases? Would they give back more weight to vowels when processing words produced in a highly familiar voice or words that explicitly tag significant "who" content, such as their own name? One testable implication of this idea would be to explore the modulation of the consonant bias in lexical processing, depending on whether the words to be recognized are more "who"-relevant or "what"-relevant. A recent study suggesting a weaker consonant bias when processing mispronunciations of their own name (von Holzen, Rider, & Nazzi, 2017) versus mispronunciations of familiar (mostly object) words (Poltrock & Nazzi, 2015) indirectly supports this hypothesis, which would need to be directly tested. If these predictions were met, it would bring new insights into how meaning shapes both early word learning and early speech (phonological) perception, and the interplay between both.

The course of language acquisition thus seems to be one in which infants first acquire some skills in recognizing talker differences, which focuses attention on vowels (the most salient parts of the speech signal), before they begin to extract linguistic units, which will require them to exploit (in most languages) the interplay between consonant perception and processing of lexical forms. This shift allows them to rapidly expand their (receptive) vocabulary and also rapidly advance their ability to discover new word forms. Being better word learners in turn opens up access to new avenues of meaning, including syntax, that infants can then exploit to refine their vowel perception. This highlights the fact that although the "who" and "what" sides of the signal are distinct, their processing is functionally integrated, as suggested by research on adults. For example, adults are better at learning to recognize talkers in their native language than in an L2, and dyslexics show impairments in both native language talker recognition and phonological processing (Perrachione, Del Tufo, & Gabrieli, 2011). Talker recognition and reading skills are also positively correlated in adults without reading impairment (Kadam, Orena, Theodore, & Polka, 2016).

Therefore, as we adopt a view of language acquisition in which speech perception and processing of meaning are seen as co-evolving skills, we might also consider how these interacting processes may be guided by developmental biases; in the search for meaning, "who" comes before "what" and vowels come before consonants, while in the discovering of the "what" side of the message, consonants come before vowels (in many languages).

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Commentary on "Perceptual Beginnings to Language Acquisition" by Janet Werker

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It is hard to think of an area of infant language development that has not been shaped, in some way, by Dr. Janet Werker. Her early work on experience-driven changes in speech perception deeply altered our field's conception both of the nature of speech perception and, more important for her future research, the nature of the type of learning performed by young infants. In aggregate, Werker's research provides an exceptionally nuanced picture of the mind of the infant, seeking and discovering structure in the world without external instruction or reward. Her research over the subsequent decades has pushed deeper into these results, greatly increasing our understanding of the types of learning that underlie

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