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Early language experience and underspecified phonological representations

doi:10.1017/S0142716417000285

Taking as a premise that phonological working memory (PWM) influences later language development, in their keynote article, Pierce, Genesee, Delcenserie, and Morgan aim to specify the relations between early language input and the development of PWM in terms of separable influences of timing, quantity, and quality of early language input. We concur that prior work has established that PWM and language development have reciprocal influences on one another during development (e.g., Baddeley, Gathercole, & Papagno, 1998; Gathercole, 2006; Gathercole, Hitch, Service, & Martin, 1997; Metsala & Chisolm, 2010). The goal of the keynote article was to describe how early language experience may influence the development of PWM. Pierce et al. argue that this can be done by comparing the development of PWM across groups of children with differing language experiences during early childhood, specifically (a) delayed exposure to language, (b) impoverished language input, or (c) enriched language input. The authors suggest that this comparison may contribute to establishing that individual differences in PWM are due, in part, to early language experience. Sensitive periods for phonological development that are open roughly in the first year of life are discussed, and it is suggested that the quantity and quality of early language input shapes the quality of phonological representations. Efforts to specify mechanisms by which early language input may influence the development of PWM have both theoretical and, potentially, clinical importance. Considering this, Pierce et al.'s article, which

https://doi.org/10.1017/S0142716417000285 Published online by Cambridge University Press

aims to create a platform for future research in terms of the timing, quantity, and quality of early language input, is a valuable contribution.

We were especially interested in the authors' exploration of the role of early language experience on PWM and language outcomes. We are reminded of work in our laboratory, which has used "process" and "product" measures of speech and language performance. Process measures have included tasks that tap PWM, such as memory span for sequences of spoken digits, nonword repetition, and verbal rehearsal speed. We have used these process measures in order to better understand "product" measures, such as speech perception and expressive and receptive language outcomes, in deaf children who use cochlear implants (CIs; e.g., Pisoni, Cleary, Geers, & Tobey, 1999). Our findings have been consistent with the principle that phonological processing, which includes the rapid phonological encoding and storage of incoming speech signals, is crucial to spoken language development (Baddeley et al., 1998; Gathercole, 2006). Further, our findings support the generalization of this principle to the population of deaf children who receive CIs. It appears that "process" measures that tap PWM are related to and strongly predict speech and language development in children with CIs (e.g., Casserly & Pisoni, 2013; Kronenberger, Colson, Henning, & Pisoni, 2014; Pisoni & Cleary, 2003; Pisoni & Geers, 2000). Like Pierce et al., we believe that understanding the ways in which the development of PWM may be influenced by early language experience is important to the field. In their keynote article, Pierce et al. present evidence that the phonological representations that are acquired during sensitive periods of phonological development in early childhood are underspecified when language input is delayed or impoverished, and suggest that less accurate encoding of phonological information may have the consequence of reducing the effectiveness of PWM.

In discussing underspecification in CI users, we believe it is important to be clear that CI users never receive undegraded auditory input, regardless of their amount of experience with the implant. Compared to a normal-hearing ear, a CI drastically lowers the resolution of information carried by the auditory nerve. The degradation of speech input through a CI has specific consequences in terms of what acoustic–phonetic cues can be perceived from the signal. For example, it is very difficult for CI users to discriminate between voices, in large part due to the lack of temporal fine structure, which contributes to fundamental frequency or voice pitch perception in listeners with normal hearing (Chatterjee, & Peng, 2008). With respect to phonetic features, the acoustic–phonetic cues received from a CI are underspecified in a way that appears to affect certain phonetic features more than others. For example, most CI users are able to discriminate minimal pairs of phonemes that differ only on a phonetic feature of the manner of articulation (e.g., fricatives vs. stops) with a high level of accuracy after a few years of experience with their implants, but are less accurate for minimal pairs that differ on a place of articulation feature (Pisoni et al., 1999). CIs drastically reduce spectral information, which conveys most of the acoustic cues for place of articulation, but preserve the temporal envelope of the speech signal, which contains amplitude fluctuations that can convey manner of articulation cues (Shannon, Zeng, Kamath, Wygonski, & Ekelid, 1995; Wright, Frisch, & Pisoni, 1999). Thus, for CI users, underspecification is enforced by degradation of the auditory signal, such that acquisition of

https://doi.org/10.1017/S0142716417000285 Published online by Cambridge University Press

typical phonological representations cannot be expected, regardless of whether the CI is operational during early sensitive periods. Moreover, the degraded auditory signal that is conveyed by a CI affects some phonological representations more than others.

Although deaf children implanted with CIs experience both delayed and degraded language input, Pierce et al. classified prelingual CI users as experiencing delayed exposure to language but not degraded exposure to language. Although not explicitly stated, the authors may have used this classification in consideration of sensitive periods in the first year of life for phonemic category acquisition (Kuhl, 2004). Deaf children have not yet received their CIs at this early sensitive period for language, and as Pierce et al. correctly point out, their exposure to spoken language is thus necessarily delayed, even when current clinical guidelines that allow for implantation before the first birthday are followed (Dettman, Pinder, Briggs, Dowell, & Leigh, 2007). CI researchers have previously noted the potential influence of missed sensitive periods for phonemic category acquisition and sound pattern learning (Kuhl, 2004; Saffran, Aslin, & Newport, 1996) on language development in CI children (Niparko et al., 2010). Because the perceptual specialization for the sound patterns of a native language that occurs in early childhood alters the neural representation of speech sounds, missing these sensitive periods likely results in suboptimal neural connectivity for spoken language processing (Kral, Kronenberger, Pisoni, & O'Donoghue, 2016). This may partially explain why age of implantation has a strong impact on individual difference in CI outcomes, and is consistent with the idea that sensitive periods for phonological input are important for specializing perception for the phonological features that are available from the signal that is transmitted to the auditory nerve by a CI. Pierce et al. correctly note at various points in their discussion that prelingual CI users experience degraded language input, although this is not reflected in their classification of CI users as delayed in language input but not as experiencing impoverished language input. Although we would have classified CI users differently than the authors, the classification may be superfluous to the general framework presented by Pierce et al. given that their analysis finds that delayed and degraded input have the same overall effect, namely, that of decreasing PWM and language abilities. For both delayed and impoverished language input, it is hypothesized that this occurs via the acquisition of underspecified representations during sensitive periods of phonological development.

In sum, Pierce et al. have made progress by setting up a broad framework for understanding the effects of the quantity and quality of early language input on phonological representations, particularly in terms of how underspecified phonological representations may affect working memory and, ultimately, language development. The authors aimed to provide a general framework for understanding the influence of early language experience on PWM. In our commentary, we note that this approach has limitations. For example, there is a lack of clarity in the terms *underspecified*, *weak*, and *less accurate* used to describe the phonological representations of children who receive delayed and/or degraded speech input early in life. Although the lack of clarity may be essential given the broad scope of this keynote article, we note that the type of signal degradation that is present for various populations, such as CI users, children who experience early bouts

https://doi.org/10.1017/S0142716417000285 Published online by Cambridge University Press

of otitis media, and signing deaf children born to nonsigning hearing parents, is likely to be different, and consequently to create different types of underspecification. We are hopeful that given the framework established by Pierce et al., future work may compare the ways in which phonological representations are underspecified for such populations. It is our view that this could potentially reveal new research directions in terms of understanding the relation(s) of phonological representations, working memory, and language outcomes across these populations.

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The importance of grain size in phonology and the possibility that phonological working memory is epiphenomenal

doi:10.1017/S0142716417000297

Pierce, Genesee, Delcenserie, and Morgan have provided an innovative and thought-provoking juxtaposition of the putative role played by phonological working memory (PWM) in explaining individual and group differences among early internationally adopted (IA) children, deaf children with cochlear implants, simultaneous and sequential bilinguals, children who are learning sign languages, and children with otitis media. This novel comparison suggests that adequate exposure to phonology before 12 months of age is key in the development of improved PWM. Consequently, long-term linguistic advantages in vocabulary and learning of morphosyntax arise, but not advantages in other areas of higher cognition. One significant implication of the review is that although many intriguing links exist between language development and PWM, irrefutable conclusions elude the field as to the directionality of a causal relationship between phonological development, other linguistic development, and PWM. In this commentary, I should like to make the somewhat controversial proposal (Gathercole, 2006, and commentaries) that the evidence presented points to PWM being an epiphenomenon arising out of individual differences in the robustness and richness of phonological representations themselves. The authors hinted several times at the tantalizing relationship between phonology and PWM, but they do not articulate explicitly that PWM could be a redundant construct. I also offer some proposals as to how one might test this suggestion experimentally or in a corpus of child language.

The evidence for PWM being an epiphenomenon derives from the review in the following way: knowledge of phonology precedes PWM; bilingualism or multilingualism from birth leads directly to higher PWM; the effect of PWM disappears by around age 5 when vocabulary knowledge predicts WM; for deaf children with cochlear implants, PWM is reliably lower than for IA children, but otherwise they are developmentally normal, suggesting that early *sound* exposure is key for PWM, not an independent "capacity" that PWM measures separately; and finally, older children who learn a second language do not have better PWM initially, but they do once the second language and expanded phonological inventory has been established.

The main problem for the construct of PWM independent of language in the literature presented lies in the dangers of circularity and correlation. The "P" in

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