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The influence of children's exposure to language from two to six years: The case of nonword repetition

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ABSTRACT

Nonword repetition (NWR) is highly predictive of vocabulary size, has strong links to language and reading ability, and is a clinical marker of language impairment. However, it is unclear what processes provide major contributions to NWR performance. This paper presents a computational model of NWR based on Chunking Lexical and Sub-lexical Sequences in Children (CLASSIC) that focuses on the child's exposure to language when learning lexical phonological knowledge. Based on language input aimed at 2–6 year old children, CLASSIC shows a substantial fit to children's NWR performance for 6 different types of NWR test across 6 different NWR studies that use children of various ages from 2;1 to 6;1. Furthermore, CLASSIC's repetitions of individual nonwords correlate significantly with children's repetitions of the same nonwords, NWR performance shows strong correlations to vocabulary size, and interaction effects seen in the model are consistent with those found in children. Such a fit to the data is achieved without any need for developmental parameters, suggesting that between the ages of two and six years, NWR performance measures the child's current level of linguistic knowledge that arises from their exposure to language over time and their ability to extract lexical phonological knowledge from that exposure.

1. Introduction

Vocabulary acquisition is an essential part of language learning, enabling the child to build a lexicon that can be used by other processes such as sentence production. Vocabulary size can be indexed by performance on nonword repetition (NWR), a simple task whereby children repeat aloud nonwords that are spoken to them. Although children's NWR performance has very strong links with vocabulary learning in particular (e.g., Baddeley, Gathercole, & Papagno, 1998; Gathercole, 2006; Hoff, Core, & Bridges, 2008), it is also predictive of general language ability (e.g., Marton & Schwartz, 2003; Thal, Miller, Carlson, & Vega, 2005), reading success (e.g., Hansen & Bowey, 1994; Kamhi & Catts, 1986) and difficulties with language or reading (e.g., Bishop, North, & Donlan, 1996; Montgomery, 1995; Snowling, Goulandris, Bowlby, & Howell, 1986). Performance on NWR tests therefore capture key mechanisms that are involved in the child's vocabulary learning that ultimately influence language acquisition more generally. However, the underlying processes involved in repeating nonwords are quite broad (Bowey, 2001; Coady & Aslin, 2004; Snowling, Chiat, & Hulme, 1991), leading to differing accounts of what NWR actually measures. Resolving this issue is the focus of the current paper.

Phonological working memory is seen as playing a pivotal role in vocabulary learning because in order to repeat a sequence of sounds one must first be able to store the sequence in temporary memory (Baddeley et al., 1998). The dominant view of NWR (see Melby-Lervåg et al., 2012) is that it is a pure measure of phonological working memory. Under this explanation, differences in NWR performance that are seen within and across ages is largely due to differences in phonological working memory (e.g., Baddeley et al., 1998; Gathercole & Baddeley, 1989). The phonological working memory account also explains robust length effects that are found in NWR whereby long nonwords are consistently repeated less accurately than short nonwords (e.g., Gathercole & Baddeley, 1989; Jones, Tamburelli, Watson, Gobet, & Pine, 2010). Nevertheless, this explanation is somewhat confounded by NWR also showing strong links to long-term lexical phonological knowledge, defined here as knowledge of the individual sounds, sound sequences and lexical items of the native language. For example, children repeat nonwords that are judged as wordlike more accurately than nonwords that are not judged as wordlike (e.g., Gathercole, 1995; Munson, Kurtz, & Windsor, 2005) and similarly nonwords constructed from phoneme sequences that occur

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frequently in the native language are repeated more accurately than nonwords constructed from relatively infrequent phoneme sequences (e.g., Jones et al., 2010; Munson, 2001).

An alternative view of NWR is that it measures phonological sensitivity because children's performance on phonological awareness tasks has been shown to be more predictive of vocabulary size than NWR (e.g., Metsala, 1999). Children's vocabulary learning is seen by many to begin with holistic forms (e.g., Fowler, 1991a, 1991b; Storkel, 2002; Treiman & Breaux, 1982; Vihman & Velleman, 1989; Walley, 1993). Later restructuring of lexical items to include segmental detail is driven by a need to have a more fine-grained account of similar words in order for them to be differentiated (Charles-Luce & Luce, 1990; Metsala & Walley, 1998; Walley, 1993). Consistent with this account, Metsala found superior phonological awareness for familiar over unfamiliar words and for words from dense over sparse neighborhoods. The segmental detail of words from dense neighborhoods, because their characteristics overlap with other words, is likely to be learned more quickly than words from sparse neighborhoods (see also Edwards, Beckman, & Munson, 2004). Since familiar words tend to be from dense neighborhoods (Vitevitch & Luce, 1998), segmental detail will also be learned more quickly for familiar over unfamiliar words. This contrasts with a phonological working memory account because it suggest that the driving force in NWR performance stems from elaborating long-term linguistic knowledge rather than constraints on temporary storage of information. However, it is unclear how the phonological sensitivity account explains length effects that are routinely seen in NWR performance (but see Metsala & Chisholm, 2010, for discussion on this point).

Both of these accounts either implicitly or explicitly recognize the role of the child's exposure to language. For phonological working memory, findings such as greater repetition accuracy for word-like nonwords over non-wordlike nonwords suggest that exposure to language must influence the NWR process. Combined with theoretical positions that suggest the effective size of phonological working memory is influenced by long-term knowledge (e.g., Miller, 1956; Gobet et al., 2001; Cowan, 2001), one could argue whether NWR truly measures phonological working memory or whether it is a reflection of the child's current level of linguistic exposure (see also Gupta, Lipinski, Abbs, & Lin, 2005; Snowling & Hulme, 1994). For the phonological sensitivity account, holistic representations of words are elaborated based on their similarity to other words, a process that is driven by increased exposure to language. Empirical investigations of vocabulary learning have also found a major role for language exposure. For example, Fernald and colleagues have shown that children who receive extensive child-directed speech or diversity in their language input have larger vocabularies than children who do not (e.g., Hurtado, Marchman, & Fernald, 2008; Weisleder & Fernald, 2013); Hoff and Naigles (2002) highlight the quantity and richness of the input, suggesting language exposure may play a greater role than social factors in children's language learning; Huttenlocher, Haight, Bryk, Seltzer, and Lyons (1991) show that individual differences in children's vocabulary growth are linked to the amount that is spoken to them by their mother; and numerous computational accounts have used language input to simulate a range of language phenomena (e.g., Brown, Preece, & Hulme, 2000; Goldwater, Griffiths, & Johnson, 2009; Hartley & Houghton, 1996; Monaghan & Ellis, 2010; Perruchet & Vinter, 1998).

Although the child's exposure to language could be seen as supporting the phonological sensitivity account, this explanation suggests that NWR performance is influenced by phonological information that emerges from restructuring of the lexical item. There is now sufficient evidence to challenge this view, suggesting that children's segmental knowledge is present from a very early age (e.g., Basirat, Dehaene, & Dehaene-Lambertz, 2014; Coady & Aslin, 2003, 2004; Gervain, Macagno, Cogoi, Pen, & Mehler, 2008; Yoshida, Fennell, Swingley, & Werker, 2009).

There are two key computational accounts of NWR that learn from their exposure to language and capitalize on research that supports a bottom-up approach.[1] Gupta and Tisdale (2009) adapted a neural network model of serial order by Botvinick and Plaut (2006) using as input 125,000 syllabified words. Long-term knowledge (the patterns of weights across the units of the network) represented gradually more detailed phonological representations of the individual syllabified words. This interacted with phonological working memory (the temporary activations across units) such that over time, longer words and nonwords were able to be recalled. The model showed differences in NWR performance for nonwords of different lengths, for high and low phonotactic probability nonwords, and for different levels of exposure to input – effects that are also seen in children's NWR performance.

Jones and colleagues have used an alternative modeling environment originally labelled EPAM-VOC (Jones, Gobet, & Pine, 2007) but later given the more meaningful acronym CLASSIC (Chunking Lexical and Sublexical Sequences in Children, Jones, Gobet, Freudenthal, Watson, & Pine, 2014).[2] As the name suggests, this account is very much embedded in chunking (e.g., Cowan, 2001; Gobet et al., 2001; Miller, 1956) and chunk-based modeling environments (e.g., French, Addyman, & Mareschal, 2011; Servan-Schreiber & Anderson, 1990) whereby larger units of information are learned over time. CLASSIC uses phonemically-coded large-scale naturalistic input aimed at young children (e.g., mother's utterances) and learns increasingly larger phoneme sequences from an input that is constrained by phonological working memory. The model again captures many of the NWR effects seen in children, such as nonword length, wordlikeness, and age differences.

The Gupta and Tisdale (2009) model explicitly targets the phonological working memory and phonological sensitivity accounts, showing how both may apply in the NWR process. The Jones et al. (2007) model on the other hand targets the link between long-term knowledge and phonological working memory in the NWR process. Nevertheless, both accounts illustrate how exposure to language is potentially a critical factor in NWR performance. However, because the simulations in both models are largely qualitative, the *extent* to which exposure to language can *explain* NWR performance at the empirical level is left unanswered.

The purpose of this paper is twofold. First, to focus on exposure to language by using large-scale naturalistic language input aimed at children between the ages of 2 and 6 years within a model that does not utilize any developmental parameters. By keeping all parameters constant, the only "developmental" change is the linguistic knowledge that the model learns, which increases with greater exposure to language. Any differences in NWR performance over time are therefore caused by the learning that takes place on the language input rather than from developmental changes per se. Second, to provide an extensive examination of the fit between model and child by using 6 different NWR studies involving children between the ages of 2 and 6 years. If the model is able to provide both qualitative and quantitative fits to the majority of the child data, it would provide strong evidence that NWR performance is a measure of the child's current level of linguistic knowledge that is accrued from exposure to language and is not a reflection of any mechanistic developmental change.

[1] The computational accounts also address one of the problems inherent in verbal explanations of NWR: phonological working memory and long-term linguistic knowledge interact with one another (see also Chen & Cowan, 2005).

[2] This modeling environment is based on the same principles as MOSAIC (e.g., Freudenthal, Pine, Aguado-Orea, & Gobet, 2007; Freudenthal, Pine, Jones, & Gobet, 2015) and uses a similar input set. However, the Jones et al. model is based on phonological input and focuses on NWR performance whereas MOSAIC is based on lexical input and focuses on syntactic processing.