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Differentiating word learning processes may yield new insights – a commentary on Stoel-Gammon's 'Relationships between lexical and phonological development in young children'*

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Stoel-Gammon (this issue) states that 'from birth to age 2;6, the developing phonological system affects lexical acquisition to a greater degree than lexical factors affect phonological development' (this issue). This conclusion is based on a wealth of data; however, the available data are somewhat limited in scope, focusing on rather holistic measures of the phonological and lexical systems (e.g. production accuracy, number of words known). Stoel-Gammon suggests a number of important avenues to pursue, but does not discuss a critical one that is emerging in the broader literature on word learning. Specifically, recent connectionist models and adult word learning research provide evidence that greater differentiation of the cognitive processes that underlie word learning yields new insights (Leach & Samuel, 2007). This approach may be fruitful for future investigations of the relationship between phonological and lexical development in young children.

Connectionist models highlight the need to consider TRIGGERING, the process of determining whether existing representations sufficiently match the input, leading to either: (1) allocating a completely new representation (in the case of a mismatch); or (2) updating an existing representation (in the case of a match: Li, Farkas & MacWhinney, 2004). Triggering processes are crucial to models that both learn new representations and recognize existing representations as a means of addressing the stability–plasticity dilemma (Carpenter & Grossberg, 1987). Specifically, models that do not incorporate this type of process show catastrophic interference where learning of new items 'overwrites' previously learned items. Triggering solves this problem by establishing a threshold (i.e. the vigilance parameter: Li *et al.*, 2004) for determining whether the input sufficiently matches existing representations.

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Studies of adult word learning support the importance of differentiating CONFIGURATION, the process of storing information within a representation in long-term memory, from ENGAGEMENT, the process of integrating the newly created representation with similar existing representations in long-term memory (Leach & Samuel, 2007). Research in this area suggests a distinct timecourse and neural basis for each process. Specifically, configuration appears to occur during training, whereas engagement appears to occur after training, with some evidence that sleep may be crucial (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Tamminen & Gaskell, 2008). This has lead to the hypothesis that configuration is characterized by swift episodic learning supported by the medial temporal lobes (i.e. hippocampus), whereas engagement is characterized by slower memory consolidation supported by cortical language areas (Davis & Gaskell, 2009).

To illustrate these processes, consider a typical word learning scenario where a child hears a novel word paired with a novel object. The new word likely will not perfectly match any existing representations, thus a new representations will be allocated (i.e. triggering in the case of mismatch). The sound structure of the word will then be stored in this new representation in long-term memory (i.e. configuration). It is likely that this new representation will be incomplete following this limited exposure. Upon subsequent re-exposure to the word, the previously created representation will be identified as matching the input (i.e. triggering in the case of a match) and will be further elaborated through storage of additional details of sound structure in long-term memory (i.e. configuration). At some point, this newly created representation in long-term memory will form connections with similar existing representations in long-term memory (i.e. engagement), allowing the new representation and existing representations to influence one another during spoken language production and comprehension.

Studies of child word learning to date have not incorporated measures that discriminate triggering versus configuration versus engagement. However, these processes have proven to be useful for interpreting results from our studies examining the effect of characteristics of the ambient language on word learning by typically developing preschool children. A recent series of studies differentiating the role of PHONOTACTIC PROBABILITY, the likelihood of occurrence of a sound sequence, from that of NEIGHBORHOOD DENSITY, the number of phonologically similar words, showed somewhat surprising results. Specifically, phonotactic probability interacted with neighborhood density such that low probability/low density nonwords and high probability/high density nonwords were learned more accurately than the two mixed conditions of low probability/high density and high probability/low density (Hoover, Storkel & Hogan, 2010). Note

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that computation of phonotactic probability and neighborhood density based on an adult corpus converged with computations derived from a child corpus (Storkel & Hoover, 2010). Moreover, these results were not confined solely to an experimental study of nonword learning but were also found in a more naturalistic study using a vocabulary probe composed of real words (Storkel, Maekawa & Hoover, 2010). Turning to the interpretation of the results, if only one process underlies word learning, how could that process account for the rapid learning of both low probability/low density nonwords, which are unique in the language, and high probability/high density nonwords, which are typical in the language? This question is easily addressed if one assumes that different combinations of phonotactic probability and neighborhood density are optimal for each word learning process.

It is likely that triggering is more accurate and efficient when the mismatch between the input and existing representations is maximal, far exceeding the threshold for allocating a new representation. In this case, the correct outcome occurs with a new representation allocated, supporting learning of the new word. In cases where the mismatch between the input and existing representations is minimal, the threshold may not be exceeded. In this case, an existing representation is updated erroneously, delaying learning of the new word. We have found that children learn low probability nonwords more accurately than high and that this effect is observed early in testing (Storkel & Lee, in press). Similarly, at early test points, children learn low density nonwords more accurately than high (Storkel & Lee, in press). Finally, low probability/low density arises as one optimal combination when probability and density are crossed (Hoover *et al.*, 2010; Storkel *et al.*, 2010). In the model, existing phonological representations are activated upon hearing a sound sequence and spread activation to existing lexical representations. In the case of low probability, these phonological representations are minimally activated, spreading minimal activation to existing lexical representations. Density determines the number of existing lexical representations that are activated. In the case of low density, few existing representations are activated. Thus, both low probability and low density yield the lowest activation of the fewest existing representations, maximizing the mismatch between the input and existing representations. Consequently, a new representation is allocated.

It is likely that configuration is dependent on working memory. That is, a novel sound sequence must be held in working memory so that the details of the sound sequence can be stored in long-term memory (i.e. configuration). Working memory studies show that high probability (Edwards, Beckman & Munson, 2004; Gathercole, Frankish, Pickering & Peaker, 1999; Thorn & Frankish, 2005) or high density nonwords are recalled better than low probability or low density nonwords (Roodenrys & Hinton, 2002; Thomson, Richardson & Goswami, 2005; Thorn & Frankish, 2005). Thus, configuration should be more accurate and/or faster for high probability and high density nonwords than for low probability and low density. Our word learning data support this hypothesis (Hoover *et al.*, 2010; Storkel *et al.*, 2010). In the model, existing phonological and lexical representations are activated upon hearing a sound sequence. In the case of high probability, existing phonological representations are maximally activated, providing greater support to working memory. Thus, the high probability sound sequence will be held more accurately and/or for a longer time period in working memory, enhancing information storage in long-term memory. In the case of high density, many lexical representations are activated, providing greater support to working memory. Consequently, the high density nonword will be held more accurately and/or for a longer time period in working memory, enhancing information storage in long-term memory. The end result is a more accurate and detailed representation in long-term memory for high probability or high density nonwords.

In terms of engagement, the most compelling evidence comes from studies showing changes in responses to trained nonwords across a one-week interval without further training (Storkel & Lee, in press). Since these changes occur in the absence of training, they presumably result from internal processes, such as memory consolidation. In terms of phonotactic probability, performance was stable across a one-week interval without further training, suggesting that phonotactic probability may not influence engagement (Storkel & Lee, in press). In terms of density, performance for high density nonwords showed clear improvements after a one-week period without training (Storkel & Lee, in press). This suggests that the number of associations formed between a new representation and existing representations determines the amount of benefit provided by engagement. Thus, many connections, as in a high density neighborhood, strengthen the new representation, improving retention.

The multiple process framework yields insights into the role of ambient language characteristics in word learning by preschool children. Applying this framework to younger children may yield new insights into the relationship between phonological and lexical development. For example, Stoel-Gammon states that 'early patterns of lexical selection are related more to individual production preferences than to characteristics of the ambient language' (this issue). The available data leave open the question of which word learning processes are affected by production preferences. A more precise statement, based on additional research, has the potential to enhance our understanding of the relationship between phonological and lexical development across the lifespan.

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