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Reading With and Without Phonological Mediation: A Connectionist Investigation

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Connectionist models of word recognition have provided insights about basic aspects of skilled word reading and dyslexia (Sejnowski & Rosenberg, 1987; Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996; Harm & Seidenberg, 1996). Word recognition itself is a well-studied empirical domain which has provided a rich set of phenomena in which connectionist ideas of learning and knowledge representation continue to be explored.

Previous connectionist models of word recognition have emphasized the computation of the sound pattern of a word from its spelling. This emphasis has been fruitful in accounting for empirical phenomena because such a computation is tightly linked with reading acquisition, and with both developmental and acquired dyslexia.

However, the ultimate purpose of word recognition is to determine the meaning of printed words, not their sound. Important questions about the processing of print cannot be addressed within a framework that only computes a word's phonological form. The exact role of phonological information in the computation of a word's semantics, for example, is highly controversial in the empirical literature. Many researchers (Van Orden, Johnston & Hale, 1988; Lukatela and Turvey, 1994; Lesch and Pollatsek, 1993) conclude that the primary method of reading is phonological, with direct access only being used to disambiguate homophones (words whose sound pattern is identical, such as ROSE and ROWS). Still other researchers (Jared & Seidenberg, 1991) argue that many factors govern the use of the different paths, and argue that the direct route is used for skilled reading of the most frequent words.

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Such questions about the phonological mediation of word reading, and the factors governing such mediation cannot be addressed within a more traditional word recognition model, where all words are read phonologically. The purpose of the current work was to explore issues surrounding word recognition within a larger framework incorporating both the semantic and phonological forms of a word. In this framework, the orthographic form of a word can be translated into its semantics either via phonological encoding, or directly from print (see Figure 1).

A connectionist model was implemented to provide insights into the factors governing the recognition of words. The central research question to be addressed by this model is that of the division of labor (Seidenberg, 1995) between the phonologically mediated and direct routes. On this view, the two pathways are combined, and computational, domain-independent principles influence the relative contributions of the two pathways. This stands in contrast to the tenants of more symbolic, information-processing models, in which domain-specific, non-computational principles govern the discrete, all-or-nothing use of one mechanism or another (e.g. Coltheart, Curtis, Atkins, and Haller, 1993).

The model depicted in Figure 1 was implemented as a connectionist network trained using a continuous time version of backpropagation (Pearlmutter, 1989). A set of 291 monosyllabic words were selected from an online dictionary. Distributed phonological representations capable of forming basins of attraction were utilized, following on the work of Harm and Seidenberg (1996). Semantic features were constructed for the words based on the Wordnet semantic dictionary (Miller, 1990). Orthographic representations were simple slot-based representations of letter sequences.

The model was built in two steps. The first step involved constructing the pathway from phonology to semantics (the top section of Figure 1). This is because children learning to read already have a large auditory vocabulary; the existence of the ability to compute the meaning from the phonological form of a word before the onset of literacy is presumed to be an important factor in the early division of labor. This initial training created a mapping from the sound patterns of words to their semantics, and also created attractor basins within the phonological and semantic spaces.

Once this "hearing" model was trained to a reasonable degree, it was dropped into the larger full "reading" model. This model was then trained to map orthographic word forms onto both the phonological and semantic representations. The state of the model was saved at checkpoints throughout the course of training, to allow the tracking of development trends.

The relative contributions of the phonological and direct routes to semantics were analyzed to determine the division of labor between the two pathways. A statistically reliable effect of frequency was found, where high frequency words were more likely to utilize the direct route. An effect of regularity was also found, where words with a regular spelling to sound correspondence were more likely to use the phonological route. These effects broadly match those of empirical studies showing phonological effects chiefly being limited to low frequency words (Seidenberg et al., 1984; Jared & Seidenberg, 1991), and conversely semantic effects being limited to words with an irregular spelling to sound

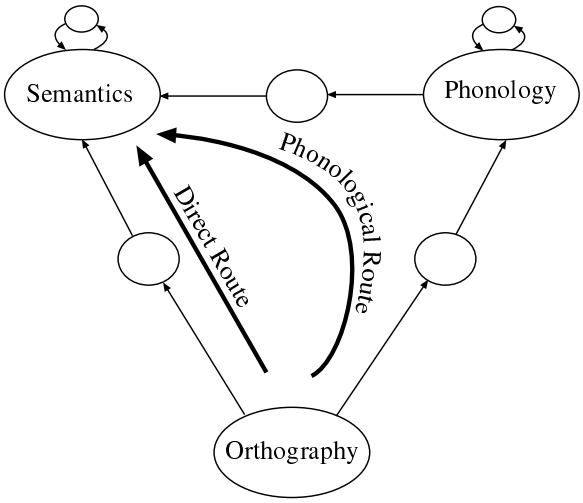

Figure 1. Implemented reading model.

correspondence (Strain, Patterson & Seidenberg, 1995).

When the division of labor analysis was conducted on the model over the course of training, interesting results were obtained. Initially, the model relied much more heavily on the phonological route. Indeed, the spelling to sound patterns were learned much more rapidly than the spelling to meaning patterns. Since the mappings from sound to meaning was already in place at the onset of reading, this caused the phonological route to be the initial way the model learned to read. However, as the model became more proficient, the demands on the model to produce the correct semantic pattern as soon as possible caused an increased reliance on the direct route. The model therefore captures not only the initial importance of the phonological route in reading, but also its reduced importance in adult skilled reading, particularly for high frequency words. Finally, the model's speed of computing the semantic code for a word is found to be dependent largely on the extent to which the direct route is utilized, providing further explanations of why phonological effects in reading tend to be more pronounced in poor readers.

The model provides an explanation of many factors that have been relevant in empirical work on skilled reading. These effects are explainable in terms of factors the model is sensitive to: the spelling to sound correspondences of words, the frequency distribution of words, and the existing knowledge about the sound to meaning patterns for words. Like earlier models of word recognition, this model provides not only a replication of empirical findings, but important insights as to why such findings arise. Further, the inclusion of semantics, and multiple access routes to semantics in a developmental model for word recognition represents a major advance over earlier models, and increases the range of behavioral phenomena that can be explored.