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Linking Behavioral and Computational Approaches to Better Understand Variant Vowel Pronunciations in Developing Readers

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Abstract

The overarching goal of the new Florida State University/Haskins Laboratory/University of Connecticut Learning Disability (LD) Hub project is to align computational and behavioral theories of individual word reading development more closely with the challenges of learning to read a quasi-regular orthography (i.e., English) for both typically developing (TD) children and, more specifically, children with dyslexia. Our LD Hub adopts an integrated approach to better understand the neurocognitive bases of individual differences in word reading development by specifically examining the experiential (exogenous) and child-specific (endogenous) factors that determine acquisition of orthographic–phonological knowledge at different subword granularities using behavioral and computational modeling. Findings are intended to enrich understanding of the processes that influence individual differences in word reading development in TD and dyslexic children and significantly inform issues of practice (e.g., curriculum, instruction, diagnosis, and intervention). Here, we briefly provide the rationale for the Hub and present findings from the initial behavioral and computational modeling studies.

Despite a growing literature on word reading development that has focused on skilled word reading performance (e.g., Perfetti, 2007; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Seidenberg & McClelland, 1989), the underlying causes of poor word reading development in individuals with dyslexia (e.g., Ehri, Nunes, Stahl, & Willows, 2001; Rueckl & Seidenberg, 2009; Vellutino, Fletcher, Snowling, & Scanlon, 2004), and the neurocognitive correlates of skilled and less skilled reading in adults and children (e.g., Pugh et al., 2013, 2014), there remain knowledge gaps in theory and practice that have hampered the development of adequate causal models of word reading. Especially important is a failure of educational research to adequately consider the implication of the quasi-regular nature of the English writing system (the relationship between orthography and phonology is systematic but admits many exceptions) for reading acquisition. As a result, many instructional programs tend to treat word irregularities as a nuisance, despite the fact that English's deep orthography (Katz & Frost, 1992) and complex historical origins (Balmuth, 1992) make complexity a central feature of the written language. Critically, ambiguity in the orthographic–phonological mapping poses significant challenges to the beginning reader. For example, Seymour, Aro, and Erskine (2003) reported that children who were acquiring reading in orthographically consistent languages (Greek, Finnish, German, Italian, Spanish) were close to ceiling in familiar high frequency word reading by the middle of first grade. In contrast, English-speaking children performed extremely poorly (34% correct). Danish (71% correct), Portuguese (73% correct), and French (79% correct) children showed somewhat reduced levels of recoding accuracy, which is in line with the reduced consistency of these languages.

Currently, there is little guidance in the literature to empirically support the design of instructional routines to improve beginning readers' ability to cope with the specific challenges presented by the quasi-regular structure of the English writing system. The NICHD supported Florida State University/Haskins Laboratory/University of Connecticut Learning Disability (LD) Hub (referred to as the LD Hub) hypothesizes that the limited effectiveness of current instructional/intervention practices for children with dyslexia stem from the fact that they fail to address these challenges (see Compton, Miller, Elleman, & Steacy, 2014). Specifically, instructional practices tend to emphasize context-independent relationships between letters and phonemes, even though much of the ambiguity in the English writing system can be at least partially resolved by taking letter context into account (see Venezky, 1999). Moreover, these practices are not sufficiently informed by evidence concerning the impact of experiential and child-specific factors on reading and reading acquisition. We further hypothesize that early reading outcomes will be enhanced by instructional strategies/procedures that directly address the quasi-regular structure of English, are grounded in knowledge of the neurocognitive bases of word reading development, and are sensitive to systematic individual differences in response to these strategies.

The overarching goal of the LD Hub project is to (1) expand our understanding of the basic mechanisms undergirding word reading development by exploring experiential and child-specific factors that determine acquisition of context-dependent orthographic–phonological (O-P) regularities in response to short-term word exposure in TD children grades 2–4; (2) examine factors that differentiate TD and dyslexic children's ability to acquire these regularities; (3) develop a computational (connectionist) model of the impact of short-term word exposure and its modulation by experiential and child-specific factors, fitting the model at both the population and individual level; and (4) use behavioral and neuroimaging experiments to ground the computational theory more deeply in evidence concerning the neurocognitive processes underlying the acquisition and use of O-P regularities as well as individual differences in these processes associated with experiential and individual-specific factors. To achieve these aims, our LD Hub builds on a foundation of scientific evidence concerning the neurocognitive and computational mechanisms underlying reading and reading acquisition by both TD and dyslexic individuals and the interaction between child-specific factors and properties of the writing system.

In what follows we provide: (1) a brief overview of the theoretical challenges associated with learning to read in a quasi-regular orthography along with the LD Hub activities designed to further understand typical and atypical of reading development in an opaque orthography, (2) initial results from the first behavioral study exploring the development and prediction of context-dependent vowel pronunciation in elementary readers (Steacy et al., 2019), (3) preliminary results from a computational modeling study aimed to better understand individual differences in general reading development and dyslexia (Rueckl, Zevin, & Wolf, in press), and (4) future directions for the project.

Theoretical Background and Project Aims

Evidence indicates that the organization of an individual's reading system is deeply constrained by the statistical structure of his or her writing system (Frost, Katz, & Bentin, 1987; Rueckl et al., 2015; Seidenberg, 2011; Seymour et al., 2003). In contrast to a transparent orthography (e.g., Spanish), where there is a nearly one-to-one mapping between letters and phonemes, English phonemes can be represented by either a single letter (e.g., *p* in *pan*) or letter cluster (e.g., *ph* in *graph*), and many graphemes, particularly vowels, can be pronounced in more than one way (cf. *pint* vs. *hint, bead* vs. *head*). Inconsistency in the O-P mapping poses significant challenges to the beginning reader. Whereas readers of transparent orthographies could learn to decode by acquiring a set of relationships (i.e., "rules") linking each grapheme with a particular phoneme and then applying these grapheme–phoneme conversion rules in a left-to-right fashion, thus assembling the pronunciation of a written word (or nonword), quasi-regular orthographies such as English are problematic for a reader relying on such rules. One possible alternative is for readers to rely on a whole-word recognition process, rather than decoding, to read inconsistent words. Although there is support for this idea (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), there is also important evidence for another solution to the challenges imposed by English—the formation of context-dependent connections (see Treiman & Kessler, 2006) which represent the probabilistic co-occurrences and constraints that exist between subword orthographic and phonological forms.

Our LD Hub hypothesizes that current code-based interventions designed to treat significant word-reading deficits rely too heavily on routines designed to foster "context-independent" decoding in which grapheme–phoneme connections are taught in isolation without systematically linking these relations to the context of specific words or letter contexts (see Compton et al., 2014). In doing so, current code-based interventions fail to adequately capture the difficulties involved with learning to read a quasi-regular writing system that requires children to become sensitive to the probabilistic consistencies/inconsistencies that exist across multiple subword units (see Ziegler & Goswami, 2005).

Results from this Hub project are intended to guide the development of the next generation of code-based interventions to promote context-dependent O-P relations in developing readers. Thus, one thrust of our research program is to investigate the process by which TD and dyslexic children become attuned to context-dependent regularities using a design-experiment paradigm we refer to as STEPR (Short-Term Exposure to Phonological Regularities). In this paradigm, over the course of three days children are presented with words embodying different mixtures of O-P regularities and receive feedback emphasizing regularities of different grain sizes. While we expect that the outcome of these manipulations will yield important insights about the processes by which children learn to decode, we believe that three additional aspects of our research program will prove crucial to gaining the scientific knowledge needed to improve instructional practices generally, and particularly for RD children.

First, it is clear that learning-related changes in the reading system arise from complex interactions between experiential and child-specific factors related to word reading development (see Whitehurst & Lonigan, 1998). As such, we hypothesize that sensitivity to, and knowledge of, the statistical regularities and co-occurrences between orthography and phonology varies as a function of the strength of a child's underlying neurocognitive skills that facilitate item-level learning (e.g., nonword reading, phonemic awareness skill, grapheme–phoneme correspondence knowledge, and statistical learning skill), the ability to generalize statistical regularities across a set of learned items, the corpus of words the child has been exposed to, the level of subword processing employed while processing words, and instructional history (e.g., experience with explicit and systematic phonics instruction).

Second, we hold that a fruitful approach to understanding neurocognitive processes (such as those involved in reading and reading development) is to ground them in a computational model that provides an explicitly mechanistic account of these processes (see Rueckl, 2016). To accomplish these goals, we adopt the triangle model framework. The triangle model is a theory of reading based on principles of the connectionist or Parallel Distributed Processing (PDP) framework (Harm & Seidenberg, 1999, 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). Computational implementations of the model have simulated a variety of aspects of reading, including aspects of skilled adult reading, reading acquisition in typically developing and learning-disabled children, acquired dyslexia, and the impact of reading interventions (see Rueckl & Seidenberg, 2009, Seidenberg, 2012, for reviews). A key insight underlying the success of this theory is the appreciation that the organization of the reading system is strongly constrained by statistical regularities in the mappings between orthographic, phonological, and semantic codes, and in particular the model provides an understanding of how O-P regularities at multiple-grain sizes are acquired and shape the reading process (Plaut et al., 1996; Yang, Shu, McCandliss, & Zevin, 2013). Moreover, the model provides a framework for systematically investigating how experiential and person-specific factors constrain the organization of the reading system. One goal of the LD Hub is to conduct a series of computational modeling simulations to deepen our understanding of both the effects of our experimental manipulations and the modulation of those effects by individual-difference variables.

Finally, our approach is deeply grounded in an understanding of the neurobiological mechanisms underlying reading and reading development. Reading engages a distributed network of primarily left hemisphere (LH) cortical regions, including occipitotemporal (OT) and temporoparietal (TP) sites and anterior circuits centered in the inferior frontal gyrus (IFG), and the computational role of these regions in word recognition is now reasonably clear (for reviews, see Graves, Desai, Humphries, Seidenberg, & Binder, 2010, Rueckl & Seidenberg, 2009, Welcome & Joanisse, 2012). Indeed, recent neuroimaging research has elucidated not only how the brain subserves reading, but it has also shed light on the neurocognitive processes by which children learn to read. For example, results from Pugh et al. (2013) and Preston et al. (2010) have revealed the importance of subcortical structures including the basal ganglia and thalamus in establishing this network in initial print learning, and connectivity analyses that have shed further light on the functional interactions of these regions (Hampson et al., 2006; Mechelli et al., 2005; Seghier & Price, 2009) in reading and other forms of skill acquisition. Critically, this research has also revealed important differences between dyslexic and TD readers with regard to activity and especially functional connectivity at each of the key LH cortical networks during language and reading-related tasks (Pugh et al., 2000; Pugh et al., 2013; Richlan, Kronbichler, & Wimmer, 2009). This "neurophenotype" of reduced LH posterior activation and functional connectivity in dyslexia appears to be stable across a large number of studies to date.

In the next two sections we describe the initial work of the LD Hub designed to combine behavioral and computational modeling approaches to increase understanding and integration of the neurobiological and cognitive underpinnings of word reading performance across the early elementary grade span. We start by describing the rationale and results from Steacy et al. (2019) exploring child- and word-factors that explain individual differences in children's use of high and low frequency vowel pronunciations in nonwords with variable vowel pronunciations. We then turn to the first computational modeling study (Rueckl, Zevin, & Wolf, in press) coming from the LD Hub exploring the effects of various control paramenters on network learning of word learning.

Context-Dependent Vowel Pronunciation

In English, much of the ambiguity associated with the pronunciation of a particular grapheme, in particular vowels, can be resolved by considering the context in which they occur (see Venezky, 1999). For instance, *ea* is pronounced as /i/ in beat, /ɛ / in head, and /eɪ/ in steak. Because /i/ is the most frequent of these pronunciations, a decoding system that operates on each grapheme independently would misread *head* and *steak*. However, if the consonant following the vowel (i.e., the coda) is taken into account, then /i/ is the most frequent pronunciation in *–eat* but /ɛ/ is the most frequent pronunciation in *–ead*. In a corpus analysis, Kessler and Treiman (2001) found that the consistency of vowel pronunciations increases significantly when the syllable coda is considered. Thus, a decoding process based on multigrapheme units could successfully decode both *beat* and *head*. (Note that *steak* and *great* would still be misread. In some cases, the only context that reliably indicates the correct pronunciation is the whole word.)

There is substantial evidence that both children and adult readers make use of knowledge of regularities involving units larger than individual graphemes and phonemes. For example, Treiman, Kessler, and Bick (2003, 2006) observed that how readers pronounce a nonword containing ambiguous vowel (e.g., *ea*) depends on the context in which it occurs. Thus, whereas *cheam* is almost always read as rhyming with *beam*, *chead* is sometimes read as rhyming with *bead* and sometimes as rhyming with *head*, suggesting that the decoding process is sensitive to the context in which a grapheme appears. The Treiman et al. (2003, 2006) studies demonstrate that this sensitivity to grapheme context develops early (i.e., first grade) and continues through elementary school (i.e., fifth grade) and is most pronounced in adults. Overall, the results of Treiman, Kessler, Zevin, Bick, and Davis (2006) suggest that children become sensitive to the statistical regularities representing context-dependent O-P relationships that exist in the English orthography.

Kessler (2009) and Treiman et al. (2003, 2006) provide two important caveats regarding the results that helped motivate the current study. First, the rate of critical vowel pronunciations (i.e., rate of statistical pattern use) in experimental nonwords (e.g., *pook* pronounced as /pʊk/), in both children and adults, was lower than that found in the general corpus of words. Treiman et al. (2003) suggest that the use of the minority vowel pronunciation (i.e., *ea* as /ɛ/) versus the majority vowel pronunciation (i.e., *ea* as /i/) is likely the result of some form of trade-off between vowel GPC frequency and strength of context-dependent O-P relationships in the rime unit throughout the corpus of English words. Second, children at lower reading levels (in particular first-grade readers) did not show universal effects across all of the nonword patterns in the experiments. Kessler (2009) speculated that young children are more likely to pay attention to context when there is no candidate that clearly dominates across contexts, suggesting that there is a "payoff" for learning to use conditional relationships when the vowel GPC is highly variant. Taken together, the Treiman et al. (2003, 2006) findings seem to suggest that the pronunciation of variant vowels in nonwords by developing readers are driven by both generalizations of vowel GPC frequency (the most common pronunciation of a vowel across all contexts) and support of context specific O-P relationships (how vowels are pronounced in particular contexts) within the corpus of English words. However, little is known about how these two knowledge sources compete during the pronunciation of nonwords with and without context-dependent connections in developing readers.

Our first behavioral study coming from the LD Hub (Steacy et al., 2019) explored how these two knowledge sources compete during the pronunciation of nonwords with and without context-dependent connections in developing readers Grades 2–5. Specifically, we extend the Treiman et al. (2006) study by considering a more diverse set of nonwords, partitioning item variance across nonwords and participants using explanatory item response models (EIRMs; a form of item response theory), and including a diverse set of participant predictors (e.g., phonemic awareness, rapid automatized naming, set for variability, visual statistical learning, vocabulary, and reading skill) and a nonword predictor (a continuous measure of the support for the alternative pronunciation of each item based on a type ratio between words containing the rime with the conditional vowel pronunciation to the total occurrences of the rime). We were particularly interested in trying to understand why some developing readers may be more willing to consider context-dependent O-P relations when reading nonwords and why certain rime patterns may have a stronger influence on supporting context-dependent vowel pronunciations than others.

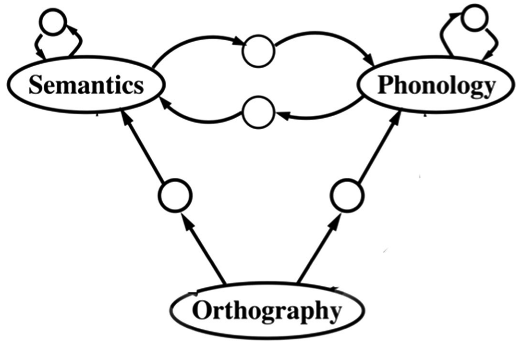
Results suggest that general reading skill at the child level and rime support at the nonword level uniquely facilitate context-dependent vowel pronunciations in our sample of developing readers. We interpret the results within a statistical learning framework as supporting a developmental model of word reading in which children are more likely to use an alternative vowel pronunciation in a nonword as they become more proficient readers and as the occurrence of the alternative vowel pronunciation is increasingly supported by the corpus of words. As would be expected in such a model of word reading development, child and corpus attributes work to "tune" variant vowel pronunciations across individual children and words, with important variance associated with both factors. Overall, our results support a model in which a different set of child-level and word-level predictors are associated with the use of more and less frequent vowel GPC pronunciations and suggest that reading skill and rime support facilitate context-dependent vowel pronunciation in developing readers.

Computational Modeling of Developmental Dyslexia

Decades of research on the mechanisms of reading have given rise to a number of sophisticated computational models (e.g., Coltheart et al., 2001; Grainger & Jacobs, 1996; Perry, Ziegler, & Zorzi, 2010). These models are in general agreement that the reading system comprises two major processing pathways: A phonological pathway by which the phonological representation of a printed word is computed using knowledge of the correspondences between sublexical orthographic and phonological units, and a lexical/semantic pathway that allows for the "direct" access to a printed word's meaning without reference to phonology. (A word's phonological representation can be retrieved "indirectly" via its lexical/semantic representation, just as its lexical/semantic representation can be retrieved "indirectly" from the representation assembled by the phonological pathway.) Although there is widespread agreement about the general structure of the reading system, the nature of the representations and processes that implement these pathways remains a matter of substantial debate. Of particular importance for the LD Hub are the processes by which the phonological representations of written words are computed within the quasi-regular English writing system.

As mentioned above, we adopt the *triangle model* (see Figure 4.1) as our theory of reading based on principles of the connectionist or PDP framework (Harm & Seidenberg, 1999, 2004; Plaut et al., 1996; Seidenberg & McClelland, 1989). In the triangle model, the reading system is instantiated in a network of neuron-like processing units that communicate by sending excitatory and inhibitory signals to one another. The network is organized into distinct "layers" (sets of nodes) responsible for representing the various

Figure 4.1. The triangle model of reading.



linguistic properties (orthographic, phonological, semantic) of the input. The connections among these layers are organized such that the triangle model includes distinct (but interacting) subnetworks mapping orthography to phonology and semantics. Each signal is weighted by the strength of the connection that it travels across. Like neural synapses, the connections in a network are plastic, and a learning algorithm is used to adjust their strengths (or *weights*) based on the interaction of the network and its task environment.

According to this model, the reading system's organization is strongly constrained by statistical regularities in the mappings between orthographic, phonological, and semantic codes. This close coupling of statistical structure and the organization of the reading system underlies the model's account of a variety of phenomena, including the role of morphological regularities in word reading (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999), changes in the division of labor between phonological and semantic processes over the course of reading acquisition (Harm & Seidenberg, 2004, Strain, Patterson, & Seidenberg, 1995), and cross-language differences in reading organization (Frost, 2012, Yang et al., 2013). Thus, this view of learning to read is largely an exercise in statistical learning. For example, as a child learning to read English encounters words such as *pin*, *mint*, and *big*, the repeated co-occurrence of the grapheme *i* and the phoneme /ɪ/, the organization of the reading system becomes attuned to this regularity. Importantly, in orthographically deep writing systems, the reliability of such grapheme–phoneme correspondences varies—for example, whereas *i* most often maps onto /ɪ/, it sometimes maps to /aɪ/ (as in *pine* and *pint*). This ambiguity creates a challenge for the learning mechanism, and indeed, even in skilled adult readers, seeing the word *hint* interferes with the subsequent reading of *pint* (while facilitating the reading of *mint*). The relative strength of distributed associations between –*int* and /ɪnt/ (as in hint) and –*int* and /aɪnt/ (as in pint) will affect the pronunciation of a nonword such as *zint* to rhyme with *hint* or *pint*.

Simulations of the triangle model have been used to address a wide variety of reading phenomena. (See Rueckl, 2016, and Seidenberg, 2017, for reviews.) As with other computational models of word reading, these simulations have primarily focused on capturing the behavior of "typical" readers. One reason for this is that these models are rooted in the literature on skilled adult reading, where (until recently) experimental data are primarily characterized by measures of central tendency, and individual differences are usually treated as little more than a source of observational noise. Moreover, because many computational models lack a learning mechanism, they offer limited means of capturing individual differences—for example, exploring how variation in a model's parameters give rise to variations in behavior (see Ziegler et al., 2008, for an illustrative example). Consequently, such theories provide little insight about the processes that give rise to differences among readers—a matter of particular relevance for those who seek to understand, diagnose, and treat dyslexia.

In this light, it is noteworthy that although relatively few simulations of the triangle model have directly addressed such differences (see Welbourne, Woollams, Crisp, & Lambon Ralph, 2011, and Zevin & Seidenberg, 2006, for notable exceptions), the theoretical principles of central importance to the model's account of individual differences among readers can be articulated using several guiding principles. First, the organization of the reading system changes incrementally as it moves through its weight space as a consequence of experience with written words. Thus, changes in organization are both continuous in form and gradual in time. Second, these trajectories through weight space vary from individual to individual with differences on various "control parameters" giving rise to characteristic pattern of performance. Third, although the organization of an individual network can be equated with its position in weight space, at the level of a population of individuals this equivalence is technically and practically problematic. These principles can be explored across individual networks by characterizing a model's sensitivity to the statistical and structural properties of the writing system, including orthographic–phonological correspondences at the level of graphemes and phonemes, word bodies and word rimes, or whole words, morphological structure, and semantic imageability (see Rueckl, 2016, for further discussion.).

The first set of Hub simulations (Rueckl, Wolf, & Zevin, in press) examined individual differences in reading development among networks varying across skill levels. Specifically, the models were developed to examine whether certain constellations of control parameters are associated with "phonological" dyslexia (greater deficit on nonword naming than irregular word naming) and "surface" dyslexics (greater deficits on irregular word naming than nonword naming). A goal of the simulations was to provide a more systematic exploration of the model's parameter space than Harm and Seidenberg (1999) were able to perform. Thus, we conducted over 2,000 simulations of the model, independently varying three control parameters:

the amount of noise added to the activation of the phonological units, the number of hidden units mediating the mapping from orthography to phonology, and the parameter scaling the step size of the weight changes resulting from each learning trial. In the Harm and Seidenberg simulations, increasing the phonological noise parameter resulted in the pattern of impairment associated with phonological dyslexia, whereas reducing the number of hidden units or the learning step size resulted in surface dyslexia.

Each of the three control parameters were manipulated over 7–10 levels, and most of the possible combinations of the settings of the three parameters are represented in the results. (Some networks with extreme values of more than one parameter exhibited minimal learning. These networks were excluded from the analyses.) Each run of the model was trained for one million trials with a training set that included 5,870 monosyllabic words. At nineteen points over the course of training the model was evaluated using a test set that included a subset of the trained words as well as a list of nonwords taken from Treiman et al. (2006).

Several general findings are worth noting. Not surprisingly, accuracy increased over the course of training. Moreover, performance varied as a function of stimulus type in a manner consistent with both human and previous simulation data. High-frequency words were read more accurately than low frequency words. Similarly, spelling-sound consistent words (e.g., *mint*) were read more accurately than irregular words (e.g., *pint*). On average, words were read more accurately than nonwords, although the magnitude and direction of this lexicality effect varied somewhat depending on specific stimulus properties as well as the amount of training. Finally, each of the control parameter manipulations affected overall performance in a manner consistent with the results of previous simulations. On average, accuracy decreased as the amount of phonological noise increased, the number of hidden units decreased, and the learning step size diminished. In addition to these main effects, the results also revealed two-way interactions of each combination of manipulations. A simple summary of these interactions is that the costs of a suboptimal setting of one parameter are magnified by suboptimal settings of the other parameters.

From a dyslexia perspective, our simulation results are consistent with Harm and Seidenberg's major findings: (i) among the networks that learned the slowest, some exhibited relatively poorer performance on nonwords than on irregular words and others exhibited the opposite pattern; (ii) these differences were systematically related to the control parameters in that networks with high levels of phonological noise tended to name nonwords relatively poorly, whereas networks with too few hidden units or step sizes that were too small were more impaired in the naming of irregular words; and (iii) deficits in nonword naming were associated with learning trajectories that differed from those of most of the better-learning networks, whereas the trajectories of slow-learning networks that struggled more with irregular words were similar to the trajectories of networks that learned at a faster rate. Our future simulations will attempt to link network performance with the child-level data collected using the STEPR paradigm to explore whether we can accurately model the effects of various control parameters associated with individual differences in experiential (exogenous) and child-specific (endogenous) factors that determine acquisition of O-P knowledge at different subword granularities using behavioral and computational modeling.

Future Directions

Our LD Hub combines behavioral, computational modeling, and neurocognitive methodologies to increase understanding and integration of the neurobiological and cognitive underpinnings of word reading performance across the early elementary grade span with an emphasis on factors that explain individual differences, elucidate the complex relationship between experience and an array of cognitive skills that represent RD, and inform effective instruction and remediation in a quasi-regular writing system. This is accomplished by (1) the acquisition of large-scale data sensitive to individual differences in context dependent/independent code learning in at-risk learners at different stages of literacy learning, (2) focus on brain/behavior designs and analyses to explicate neurocognitive factors that impact reading, and (3) focus on computational models to predict individual differences in reading deficits. As work on this LD Hub progresses, the behavioral and computational modeling outlined above will become increasingly integrated. The behavioral data collected using the STEPR paradigm will be used to generate and test new computational models intended to better understand neurocognitive bases of individual differences in word reading development. To model STEPR instruction computationally, networks will be trained on exactly the same words as in a given training condition with networks compared the results to the behavioral data. Findings will allow us to explore which factors best support vowel tuning in typical and dyslexic children and further allow us to speculate on how word reading instruction might be modified to support development of context-dependent vowel pronunciation in struggling readers.

The LD Hub is intended to lay the scientific foundation for a generation of research that situates educational practices (e.g., diagnosis, curriculum, instruction, and intervention) in a novel computational theory of individual development informed by state of the art computational modeling and neurobiological measures of development and learning, and conversely, that aligns these theories more closely with the challenges confronting educators of both TD children and especially children with dyslexia. The primary motivation for our Hub is the realization that the next frontier of scientific work in the field of dyslexia must increase understanding and integration of the neurobiological and cognitive underpinnings of word reading performance across the early elementary grade span with emphasis on factors that explain individual differences, elucidate the complex relationship between experience and an array of cognitive skills that represent dyslexia, and inform effective instruction and remediation.

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