Helping dyslexic children attend to letters within visual word forms

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Learning to read visual words aloud requires a novel integration of two distinct neurocognitive systems: a visual system that allows one to recognize a visual word from a crowd of letter features and a phonological language system that allows one to recognize and produce spoken words from a crowd of phonetic features (1). Integrating these two systems through the alphabetic principle bestows skilled readers with the ability to appreciate how each letter feature within a crowded visual word form specifically influences each corresponding nuance in its spoken form (e.g., trails vs. traits). Children with developmental dyslexia, a condition that affects as many as 10% of school children (2), face profound challenges in fluently integrating their visual and phonological systems in the service of reading (3). As a result, reading is slow and error prone, which can have severe cascading influences on a child's life. Thus, a central focus in cognitive investigations of dyslexia has been to gain insight into how individual differences in the development of phonological and/or visual processing systems influence the reading acquisition process. Leveraging such insights to improve reading acquisition has remained a central exemplar for the potential of basic cognitive and developmental sciences to bestow translational benefits to education and society.

Significant progress has been made by focusing on the phonological side of dyslexia, providing the central insight that the alphabetic principle on which our writing system is based requires children to attend to and recognize subsyllabic features within spoken words (phonological awareness) and that deficits in this form of selective attention directly contribute to difficulties in reading acquisition (4). Moreover, translational research directed at enhancing attention to the phonological features within spoken words shows improvements in reading skills for children with dyslexia. Such findings have been well-replicated, supporting significant effects within metaanalyses (5, 6), which in turn, have influenced national policy on evidence-based reading instruction. Although substantial research efforts have focused on visual system contributions to dyslexia, such studies have not yet approached this level of support or widely adopted translational success. Recent findings, however, suggest that this asymmetry may soon be changing. The study by Zorzi et al. (7) in PNAS provides a clear demonstration of an easily measured visual phenomenon that helps children with developmental dyslexia, adding to a growing body of research that shows it to be a well-replicated, theory-driven insight into how visual–spatial attention skills contribute to dyslexia. Importantly, this research also has clear translational implications that might be readily implemented on a large scale.

Letter Spacing Effect. The work by Zorzi et al. (7) shows that a purely visual manipulation of text—changing the typeface of a standard 14-point font so as to double the spacing between the letters—immediately enhances reading performance in dyslexic children. This letter spacing manipulation allows dyslexic children ~10 y of age to read 10% more rapidly while committing roughly 50% fewer errors. This pattern of results shows that they are not simply reading faster, but better. Perhaps the most compelling aspect of this study is that the letter-spacing benefit is shown to be highly replicable. The effect not only replicated across different measurement sessions and different reading materials but also across groups of dyslexic children reading different languages: Italian and French.

Spatial attention deficits in dyslexic children might impair their ability to focus on each successive letter in a visual word.

The methods used in the study by Zorzi et al. (7) are refreshingly simple, requiring little more than a stopwatch and a few pages of text with standard and spaced letters. Such measures could be readily adopted by any group of educators wishing to replicate this effect for themselves. Likewise, the task of having children simply read text aloud provides a clear, ecologically valid measure that is likely to generalize to broader academic achievement in reading.

The letter-spacing effect in dyslexia apparently transcends geographical and linguistic boundaries, which is further evidenced by a study by Perea et al. (8). Dyslexic children in the Valencia region of Spain showed that increasing the spacing between letters of a 14-point font text significantly speeds oral reading fluency by ~10% and supports significant benefits in comprehension.

The letter-spacing effect seems to be stronger in dyslexic children than typically developing children. Across both the Italian and Spanish studies described above, letter-spacing benefits were modest to nonexistent for younger typically developing readers at the group level (8), although this leaves open the possibility that some typically developing readers might still benefit from the letter-spacing manipulation (8).

Crowding and Spatial Attention. The effect of the spacing manipulation can be understood within the framework of a more general visual-object recognition phenomenon known as *crowding*, which describes how one's ability to recognize an attended target letter is systematically degraded by the proximity (i.e., critical spacing) of adjacent letters (9). Why are dyslexic children more susceptible to the influence of crowding? The study by Zorzi et al. (7) suggests that spatial attention deficits in dyslexic children might impair their ability to focus on each successive letter in a visual word while suppressing the influence of the adjacent letters in standard typeface. Because the influence of neighboring letter features is systematically related their proximity to the attended letter, increasing the spacing between letters should reduce the interfering effects of crowding, allowing these children to more readily focus spatial attention on and recognize each successive letter within a word form. This spatial attention explanation dovetails nicely with a recent longitudinal finding that shows how weaknesses in spatial orienting within prereading children predicts reading difficulties in these same children during the first 2 y of elementary school (10). This explanation also integrates

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recent findings that variations in reading speed within a dyslexic population are systematically related to variations in their critical letter spacing (crowding) (11) and that visual crowding is reduced by spatial attention cues (12).

Does the spacing effect aid dyslexic children by allowing them to better attend to and recognize each successive letter within a visual word form? Such an explanation would provide an interesting parallel to the attention-based explanations of phonological awareness deficits in dyslexia. Unfortunately, the reading-aloud paradigm used to show the spacing effect provides little direct evidence for such a link between letter-spacing benefits and spatial attention directed to letters within words. Convergent evidence from less ecologically valid but more tightly controlled observations of word-reading information processing dynamics may be needed to help support such a theoretical link.

Fortunately, the same dyslexic children who showed the 10% letter-spacing fluency benefit in the Spanish study described above (8) also participated in a reaction time paradigm that allowed separate assessment of letter-spacing effects for longer vs. shorter visual word forms. This contrast of word length is potentially informative, because unlike adults, children's reading is highly influenced by the number of letters in a word, presumably reflecting a process of serially shifting spatial attention to each successive letter within a visual word form (13). In support of this, individual differences in the slope of 2nd grader's length effect are predicted by spatial attention skills assessed before the onset of reading instruction (10). If spacing facilitates the process of attending to and recognizing each successive letter in a word, spacing effects should be strongest for longer words. This prediction was beautifully borne out by the Spanish dyslexic children. Within the longer (six-letter) word condition, stimuli presented with increased letter spacing showed a 10% fluency benefit as well as a greater than 50% reduction in errors—recapitulating the text reading results. In contrast, letter spacing produced no benefit for the shorter word condition. Together, these conditions comprised a robust length by spacing interaction, which is consistent with letter spacing impacting a serial process that scales with word length, such as directing visual attention to each successive letter.

Does the letter spacing effect only benefit children with dyslexia? Interestingly, the reaction time paradigm described above also revealed a significant but smaller length by spacing interaction in a group of younger, typically developing readers, suggesting that the benefits of optimizing letter spacing may extend beyond children diagnosed with dyslexia.

Taken together, these findings provide a compelling insight into a specific challenge that visual word forms pose for dyslexic children. Although letters might be easily recognized in the uncrowded initial and final positions within a word form, recognizing letters in the more crowded medial positions should prove to be more attention demanding. A combination of weak spatial attention skills and an over-reliance on more readily recognized letter positions may induce a persistent bias in how children attend to visual word forms, thereby preventing children from mastering the mappings between word medial letters and their corresponding phonological representations. This possibility may help explain why dyslexic children's decoding errors occur more frequently when the very same letters appear in medial versus initial or final letter positions (14).

Gaining incremental insights into crowding in dyslexia may be relevant for efforts to overcome these difficulties by enhancing spatial attention. Short term training efforts to improve spatial attention through action video games reduces the influence of crowding (15). Other approaches, such as the Word Building intervention for dyslexic children, directs children's attention to a single letter in an uncrowded visual field and then has them drag that letter into a medial position of a visual word form before decoding the word. Such training efforts lead to improvements in visual word recognition as well as phonological awareness skills that generalize to novel material, suggesting that children develop enhanced abilities to attend to and recognize each letter position within a visual word form (14). Training induced changes in the way children attend to visual word forms may impact the eventual integration of every letter position within a visual word form with its corresponding phonological features in spoken words (14).

Overall, the central finding of letter-spacing reading benefits for dyslexic children represents a replicable, theory-driven insight with direct translational implications. Perhaps the most compelling aspect of this line of research is the presumably direct implication for accommodating the needs of children with dyslexia as well as the potential for facilitating reading skills in below average or early readers. Letter spacing is easily achieved for printed materials. Furthermore, the growing prevalence of text reading on desktop computers, e-books, and tablet computers opens up the possibility of manipulating digital text to optimize the critical spacing characteristics for each individual user.

This work provides a potential example of a direct contribution from basic research in cognitive science to education. Such lines of contribution are often difficult to trace, because the flow of information between research and practice is often reciprocal in nature (16). In this case, however, the spacing manipulation of text is a contribution unreported in educational research. David Rose, cofounder of the Center for Applied Special Technology (CAST), a nonprofit organization whose mission is to improve education for diverse learners through technology, explains why manipulating letter spacing as a potential factor has not yet been explored. "It would be a snap to implement, and is probably a good idea based on this evidence, but we just never thought of it. The success of language-based insights into dyslexia may have narrowed researchers' vision, including ours."

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