Brain Plasticity and Reading Achievement in Response to Intervention

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Abstract

Neuroimaging and cognitive models can work together to inform our understanding of reading. Reading draws upon orthographic, lexical/semantic, and phonological processing as well as spelling-sound conversion. Activation in the brain for these processes is centralized in different areas, but some overlap is visible on fMRI's. Language learning physically changes the brain. Successful training related to spelling has been shown to result in increased activation in specific areas of the brain, particularly in the left temporal lobe. For beginning readers, the brain's reading-related circuitry encompasses a broader area. It includes the parietotemporal, occipitotemporal, and inferior frontal gyrus as well as the visual cortex, precuneus, posterior thalamus, prefrontal cortex, and right hemisphere parietal and temporal networks. A better understanding of brain activity while reading can contribute to early identification of reading disabilities and suggest the types of intervention that would stimulate connections among key areas of the brain. Ongoing research is needed to identify educational applications of these neurobehavioral research findings.

Keywords: neuroimaging, reading, decoding, comprehension, achievement

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Teachers of reading can benefit from understanding the structure and functions of the brain, particularly because through instruction teachers hope to make changes in the brain. Skilled readers are able to advance their knowledge at a rate much faster than their peers with reading impairments because of what they can learn through reading. Therefore, one of the most important skills teachers can give their students is the ability to read. The results of the 2013 National Assessment of Educational Progress (NAEP) indicate that just 35% of the nation's fourth grade students read at or above the proficient level. With almost two-thirds of fourth graders in the U.S. reading at below proficient levels, there is a lot of work for teachers to do. Teachers can use the results of research in reading to inform their instructional practice.

By the same token, neuroscientists can use theories of reading to guide them as they create questions for their research. There are three major theories about how our brains process as we read that were developed long before the prevalence of fMRI. The dual-route cascaded model of reading was proposed by Coltheart in 1978. It consists of a lexical and sublexical route. The lexical route relies on the orthographic lexicon so that during fluent reading, when a reader sees a word, he activates his phonological lexicon and reads the word aloud, almost as a whole (Shaywitz & Shaywitz, 2008). Automatic reading and irregular words are processed using the lexical route through what is referred to as *addressed phonology*. The sublexical route is used for purely phonetic tasks during which the reader sequentially assembles the sounds to read the word (assembled phonology). The mechanisms in the brain that perform these tasks are separate but interrelated (Shaywitz & Shaywitz, 2008). Other reading models described by Taylor et al. are the triangle model and the connectionist dual-process model. All the models, which are described in more detail in the results section, include a phonological and a lexical/semantic/orthographic component. Taylor (2013) hypothesizes that the cognitive models can guide investigations of the brain bases of reading and that neuroimaging can support and advance cognitive models.

Neuroscientists are more readily able to study the live brains of individuals as they read due to noninvasive methods such as functional magnetic resonance imaging (fMRI). This technique has allowed researchers to determine what areas in the brain are activated while reading, thus determining what the neural reading systems are. Research facilities throughout the world now have equipment with which to conduct fMRIs in order to take neuroimages at baseline and after treatment to determine whether there have been changes in the brains of the experimental group as compared to those of the control group. Numerous studies have been conducted around the country to examine how typically developing (TD) readers process text, what differences we see in dyslexic (DYS) readers, changes in brain activation and structure after reading intervention, and how those changes are, in many cases, reflected in increases in reading achievement. Subjects demonstrated brain plasticity at all ages in response to intervention; plasticity is not limited to young children. The types of changes, however, did vary based on age. With instructional treatment, early elementary children through grade three with reading impairments were more likely to increase brain activity in the same areas of the left hemisphere as TD readers (Aylward et al., 2003; Berninger, 2013; Pugh et al., 2013; Richards et al., 2013; Shaywitz & Shaywitz, 2006). Upper elementary and middle school children showed some increases in activity similar to TD readers and some compensatory activity in symmetrical areas of the right hemisphere (Pugh et al., 2013; Richards et al., 2013). Adult dyslexics after instructional treatment showed increased activity in compensatory areas. Now that there is general agreement about what parts of the brain comprise the reading system, an emerging area neuroscientists are studying is the neural connections among the components of the brain’s reading system. Those connections affect the speed and automaticity of reading. Disruptions in the connectivity between areas impact reading skill and automaticity (Ashkenazi et al., 2013; Berninger et al., 2013; Koyama et al., 2013 Richards et al., 2006; Rekart, 2013; Wang et al., 2013).

There is a high percentage of comorbidity of ADHD and dyslexia. Researchers are beginning to examine the role of attention on reading disabilities. Some researchers hypothesize that the attentional systems in the inferior temporal cortex and the posterior parietal cortex either help or disrupt the process of selective attention to relevant stimuli that leads to rapid computational processes during reading. This is important as the brain accesses both lexical and sublexical processes to read (Berninger, Lee, Abbott, & Breznitz, 2013; Shaywitz & Shaywitz, 2008). Shaywitz and Shaywitz (2008) propose that pharmacological treatments may enhance the effectiveness of educational treatments by minimizing attentional disruptions while reading.

Ultimately the purpose of understanding how the brain works while individuals read is to be able to increase reading achievement. This author has compiled information from studies that shows a relationship between educational interventions, changes in brain activity, and improvement in reading achievement. Following a 3-week intervention, Aylward et al. (2003) found measurable changes in brain activation for phonological and morphological tasks. The dyslexic children in Aylward's study had an average of a 6 point increase on the Woodcock Reading Mastery Test, Word Attack subtest. Koyama et al. (2013) found increased intrinsic functional connectivity (IFC) between the reading centers in remediated dyslexic children who had received targeted interventions. Richards et al. (2006) analyzed fMRI brain activation responses to three different types of tasks (phonological, morphological, and orthographic) to determine the unique locations in the brain where each word form is processed. They then designed treatments that emphasized either phonological or morphological instruction. Richards et al. found that morphological instruction led to the greatest improvements and hypothesized that it was due to a crossover effect that helped the brain map the interrelationships among the word forms. Shaywitz et al. (2004) provided an experimental intervention over an eight-month period that focused on teaching the alphabetic principle. fMRIs and reading assessments were done on a control group of typically developing readers and on the experimental group at baseline, at the end of intervention, and again one year later. The experimental group made significantly greater gains on some reading measures. Post-intervention fMRIs for the control group and the experimental group had increased in similarity during reading tasks. In short, there are a number of studies that incorporate neuroimaging, treatment, and assessment. A more detailed analysis, summary, and compilation of findings of the aforementioned studies will be presented in the results section.

Method

The initial search for articles began on September 22, 2013 in the Rivier University Library Academic Search Premier database. An additional search was conducted in the International Dyslexia Association database. The search terms used were fMRI, reading comprehension, reading decoding, achievement, and literacy. Inclusionary criteria from search results were based on indications in the abstract for applicability to the subject. Successive searches were conducted on November 2, 3, 7, and 9 which yielded 20 articles, 18 of which were peer-reviewed. Upon closer examination, five of these articles were kept as references. 15 articles were rejected because they were not directly applicable to the topic. Using the five applicable articles, this author conducted an ancestral search and found seven more articles. Four researchers were identified as conducting fMRI research related to reading, and additional searches were conducted using their surnames as a search term in addition to the original search terms. The researchers whose surnames were added to the search teams were Shaywitz, Pugh, Richards, and Berninger. That search yielded six additional articles. Two articles were obtained because they were referenced in studies and then were used as a primary source.

Results

Cognitive Models of Reading

The most prevalent cognitive models of reading aloud include the dual-route cascaded (DRC) model, the connectionist dual-process (CDP+) model, and the triangle model (Taylor, 2013). While Taylor acknowledges that the models do not precisely match the neurocognitive reality, he believes they can serve as a guide when interpreting fMRIs. The DRC model is the simplest. Coltheart (2001) as cited by Taylor describes two routes the brain hypothetically takes to read aloud, the nonlexical and the lexical. The nonlexical route is purely phonetic, relying on converting letters into sounds. The lexical route takes entire known words and maps their orthography onto the phonology of unknown words. For example, the lexical route would correctly take *thought* and map it onto *bought*. However, it would not work to use the irregular word *pint* and map it onto *mint*.

The CDP+ model, as described by Perry, Ziegler, and Zorzi (2007), takes the DRC model and adds a phonological buffer so that visual input from words is processed through both the lexical and nonlexical or sublexical networks. The phonological buffer resolves any irregularities in the word and also weights the frequency of orthographic patterns in order for the phonological buffer to become increasingly accurate.

The triangle model of reading aloud has phonology, orthography, and semantics as the three points of the triangle (Seidenberg, 2004). Between each point of the triangle are what

Seidenberg calls *hidden units* that provide feedback to the brain about which strategy or combination of strategies to use to process the word. To use a simplistic example, the word *have* might go to the phonological processor because it matches the pattern of the word *gave* but then be sent to the orthographic processor to be recognized and read aloud as a whole, with the brain receiving clues about the sounds of /h//a//v/. This model recognizes the interaction between rule-based grapheme-phoneme correspondence (GPC) and irregular words.

Catinelli et al. (2013) describes a theory about how the next step, reading aloud, takes place. They propose that while reading the semantically and phonetically mapped words move from the posterior area to the frontal lobe where the information is mediated and pronounced. This process works rapidly in fluent, skilled readers.

Neuroimaging Models

Theoretical models of reading can guide researchers' analysis of fMRIs, especially as they examine typically developing (TD) readers. Understanding TD readers helps researchers more readily identify anomalies in the activity of the dyslexic brain while reading. It is important to remember that even though spoken language is innate and does not need to be taught, reading is a relatively new skill (evolutionarily speaking) that depends upon readers repurposing parts of their brain for the symbolic language task of reading. The structure of the dyslexic brain may not allow it to easily repurpose parts for reading.

There are three major areas of the brain involved in reading. The occipital-temporal (OT) area, also known as the visual word form area (VWFA), is located in the left hemisphere posterior of the brain. It is associated with fluent reading. Brain activation in this area increases with reading skill. This is where instant word recognition occurs after many repetitions (Abadzi, 2008; Shaywitz & Shaywitz, 2008). Morphological input, because it is perceived more holistically, is processed in the VWFA. Semantic processes are also handled in the OT area.

The other posterior system but more dorsal is the left hemisphere parietotemporal (PT), or word analysis, part of the reading system. The PT part of the reading system processes comparatively slowly. This is the part of the brain used to read pseudowords. It is also the area used heavily by young children as they are learning grapheme/phoneme correspondence. When we discuss phonological awareness as a recommended component of reading instruction, we are referring to activity that takes place in the PT area (Abadzi, 2008; Shaywitz & Shaywitz, 2007, 2008.)

The anterior system involved in the reading system is the inferior frontal gyrus (IFG), also known as Broca’s area. It is associated with naming, silent reading and pronunciation. The anterior system mediates information coming from the posterior reading system and determines the pronunciation of written words (Berninger et al., 2013; Shaywitz & Shaywitz, 2008).

For beginning readers, the reading-related circuitry appears to be broader. It includes PT, OT, and IFG as well as the visual cortex (cuneus), precuneus, posterior thalamus, prefrontal cortex, and right hemisphere parietal and temporal networks (Pugh et al., 2013). The authors speculate that as readers become more skilled, specialization occurs in the left hemisphere occipitotemporal area. That specialization may occur with the help of the pulvinar, which controls attentional processing.

Connections between the reading systems permit the interactions crucial to make reading possible. Wang, Bartolotti, Amaral, and Booth (2013) found that there are hubs of connectivity between the reading areas. Stronger long-range interaction was associated with greater reading accuracy. Disruptions in connectivity are associated with reading difficulties, but there is evidence to suggest that the difficulties with connectivity can be normalized with intervention (Richards & Berninger, 2008). Koyama et al. (2013) found that the intrinsic functional connectivity (iFC) between the left intraparietal sulcus (LIPS) seed and the left middle front gyrus was significant in skilled readers during reading tasks. There was a positive correlation between literacy and the strength of the iFC between LIPS and LMFG.

Connectivity and attention are closely related phenomena in the brain. Attention plays a role in how efficiently the reading system functions. Rekart (2013) states that as we focus our attention on a task, we are getting cognitive processes ready to use. Since there is a high rate of comorbidity for dyslexia and ADHD (Shaywitz & Shaywitz, 2008), it follows that individuals with reading disabilities will, in many cases, have difficulty getting ready to read. Brain differences in individuals with dyslexia are associated with difficulties with working memory and executive functioning, a slowed phonological loop, difficulty initiating and sustaining language tasks, and switching attention between different language tasks (Berninger et al., 2013). Reading practice makes the decoding process automatic, which decreases demands on working memory and in turn frees up attention for other processes (Rekart, 2013), e.g. semantics and text comprehension (Shaywitz & Shaywitz, 2008). Phonics must be practiced in order for it to be automatic so that the OT can work in tandem with the PT for more rapid word recognition. By overlearning the regular phonetic patterns, dyslexics can begin to differentiate the word-specific orthographies in which there is not complete sound-symbol correspondence, e.g. *-tion* (Berninger et al., 2013). As mentioned earlier, printed words are perceived by the brain and processed by either the lexical or sublexical areas located in the posterior of the brain. The posterior parietal cortex helps regulate attention through connections with the prefrontal cortex (PFC). The PFC shuts out irrelevant stimuli and helps individuals maintain or divide attention. The left parietal cortex has been associated with reading, dyslexia, and attention (Shaywitz & Shaywitz, 2008). As a result, individuals with dyslexia are more likely to be hampered in reading by structural differences in their brains as well as by the support mechanisms of attention and connectivity in the posterior left hemisphere.

Dyslexic and Learning Disabled Readers Compared to Typically Developing Readers

Phonological awareness (PA) is an important predictor in early reading. PA and early reading have a reciprocal effect on each other (Pugh et al., 2013). In other words, instruction in phonological awareness can help students acquire reading skills, and reading practice improves phonological awareness. Raschle, Chang, & Gaub (2011) as cited by Pugh et al. found anatomical differences in the temporoparietal and occipitoparietal areas of the brain in at-risk pre-readers, which suggested that reading difficulties can be caused by physical deficits in the areas of the brain that engage in phonological processing. Training can help develop atypical areas in the brains of dyslexic readers in the PT area and in other areas as demonstrated by neuroimaging (Pugh et al., 2013; Richards et al., 2006, Shaywitz, Lyon, & Shaywitz, 2006).

Neuroimaging now gives researchers the capability of recording activation patterns while individuals are reading. Several studies have compared and contrasted brain activity and structure for typically developing (TD) readers and dyslexic readers. Table 1 summarizes the findings of several researchers. Younger dyslexic readers who received educational intervention tended to have activation patterns similar to TD readers. Older dyslexic readers who responded to intervention tended to increase activity in the right hemisphere. Odegard et al. (2008) found that treatment responders showed an increase in activity in the right inferior frontal lobe when compared with the control group and non-responders. Koyama et al., 2013 found increased activity in the right hemisphere for treatment responders. They also found that treatment responders developed compensatory cortical changes in connectivity between the left fusiform gyrus and right middle occipital gyrus. In TD readers, the connectivity was entirely on the left.

Neuroimaging and Evidence of Response to Instruction

Shaywitz et al. (2004) completed an eight-month quasi-experimental study including 77 children between 6.1-9.4 years. It was designed to measure the effects of a phonologically-based intervention. There were 37 children in the experimental group, 12 children in a community intervention that was not phonologically based, and 28 TD readers as a community control group. Intervention was provided daily for 50 minutes and focused on teaching the alphabetic principle using both reading and spelling at the word and the text level. The experimental group also learned the six basic syllable types of English and progressed from one-syllable words to polysyllable words. Text reading practice incorporated both phonetically controlled books and, as the children progressed, trade books that were not phonetically controlled. Gains in scaled scores on the Gray Oral Reading Tests were significantly greater for the experimental intervention group (+1.7 Scaled Score) as compared to the community intervention group (-.5 Scaled Score). fMRIs done at the end of intervention and again one year later showed the experimental group had increased activation in the same areas as TD readers, and that the occipitotemporal region continued to develop one year post intervention. The authors hypothesized that once the reading systems in the LH had developed, the compensatory activity in the RH was no longer necessary.

The lessons used in the Shaywitz et al. study had five steps: 1) Review of sound-symbol associations; 2) Practice with phoneme analysis and blending by making new words with letter cards; 3) Timed fluency practice of previously learned words; 4) Reading stories orally; 5)

Dictation of phonetically regular words, during which children articulated the sounds slowly in order to build phonologic and orthographic connections.

Richards et al. (2006) reviewed eight studies that combined brain imaging and instructional treatments, one of which was by Shaywitz et al. (2004) as described in the previous paragraph. Details are available in the tables on pp. 553-560 of the article. Treatments that resulted in an increase in word reading emphasized instruction in the five components recommended by the National Reading Panel (2000): phonological awareness, phonics, vocabulary, fluency, and reading comprehension. One of the studies done by Richards et al. (2002) with upper elementary-aged children also included alternative treatments that emphasized either phonological or morphological awareness. In that study "the children who received the morphological awareness treatment improved significantly more in the rate of phonological decoding than those who received only phonological awareness treatment" (p. 554). The authors hypothesized that children in that age group can become more efficient with phonological decoding by learning to coordinate the phonological, orthographic, and morphological aspects of reading. fMRS findings showed improved efficiency from the morphological treatment as evidenced by significantly reduced lactate activation during neural metabolism.

Simos et al. (2002) as cited by Richards et al. (2002) completed a quasi-experimental study of 8 dyslexics ages 8-17 years old with 8 TD readers in a control group. The experimental group received 80 hours of phonologically based instruction during a two month period using either Phono-Graphix or Lindamood Phoneme Sequencing. After treatment, the experimental group showed increased activation in the same areas of the brain as the control group, but the peak occurred later in time in the left superior temporal gyrus. The LH increased in its activation, but the RH did not decrease. The experimental group increased in their reading skills. This author was unable to access the primary source in order to obtain specific information about the amount of increase and the assessment used.

Aylward et al. (2003) conducted a quasi-experimental study with 10 dyslexic children and 11 TD readers using the five components of reading instruction, although no further detail was given about the treatment. The total duration was 28 hours provided 2 hours per day for 14 days. The experimental group improved significantly on the Woodcock Reading Mastery Test Revised, increasing from a mean standard score of 87 (SD = 7.4) to 93.7 (SD = 10.8). They also improved on morphologic tasks as measured after treatment. fMRIs given pre and post treatment showed that brain activation for the dyslexic students changed to closely resemble the control group of TD readers.

Berninger, Lee, Abbott, & Breznitz (2013) designed a quasi-experimental study that involved improving spelling scores for the lowest achieving second graders in a school. The authors called it the rapid accelerated reading (RAP) program. The treatment group learned to use multiple strategies: grapheme phoneme correspondence (gpc); how the gpc transfers to spelling words; looking at onset and rime; naming the word; and naming each letter in the word. The control group received phonological training with spoken words. The duration of the treatment was 24 lessons twice a week during a five month period including vacations. Half of the students reached grade level during second grade. Those who did not reach grade level had additional instruction in the third grade on the six syllable types and spelling multisyllable words. Those students then reached grade level spelling. See Table 2 for a summary of the treatment for Group A and Group B as well as a description of the significant posttest changes. The authors confirmed three research findings as a result of this study: 1) “Teaching silent orthography normalized brain function on spelling tasks” (p. 16); 2) Orthographic treatment significantly increases decoding rate; and 3) RAP reading improved silent reading comprehension and rate. Berninger et al. used a six-step process to increase orthographic working memory they called the "Photographic Leprechaun" to help students learn the spelling of a word: 1) Name each letter; 2) Take a mental picture of the word; 3) Close their eyes and mentally picture the word; 4) Answer questions about the position of the letters in the word; 5) Open their eyes to check their mental picture; 6) Close their eyes and spell the word backwards.

Summary of Instructional Strategies that Resulted in Reading or Spelling Increases

- Teach the alphabetic principle and structures of the English language to include:
  - Grapheme-phoneme correspondence
  - The six syllable types
  - Morphology
- Teach phonics to automaticity through repetition.
- Reread phonetic text and uncontrolled text to build fluency. Readers' Theatre is one way to have students reread while engaging their imagination (Frey, 2010).
- Activities that can help children use the orthographic processor for rapid automatized reading include:
  - Increase orthographic working memory with visualization tasks
  - Use phonics to support orthographic working memory for irregular words.
  - Incorporate morphology instruction to aid phonology, vocabulary, comprehension, and use of the orthographic/semantic processor in the occipitotemporal area.
- Incorporate all five of the National Reading Panel recommended components for reading: phonemic awareness, phonics, vocabulary, comprehension, and fluency.

- Because written language is an abstraction of spoken language, create opportunities to interact with children using complex descriptive oral language. Expand on the child's words. For example, if the child says, "It's hot outside," the adult could respond with, "Yes, the sun is warming up the earth and all of us too. The flowers love the warmth of the sun."
- Language learning changes the brain, and areas of the brain used for spoken language are also re-purposed for reading.
- Mirror neuron systems help children learn through imitation, so it helps children learn when teachers think aloud, model, or demonstrate (Frey, 2010).
- For younger children, phonemic awareness is most robustly predictive of reading achievement. Use instructional strategies that target phonemic awareness, including onset and rime, phoneme manipulation, segmenting, and blending.
- Upper elementary and middle school students will benefit from morphology instruction (Richards, 2006).
- Adults respond most to explicit instruction in sound and articulatory awareness as well as phonics training, according to Eden et al. (2004) as cited by Richards (2006).

Summary and Implications for Future Research

Summary

Neuroimaging is continuing to be refined, as are the study designs that use neuroimaging technology. As a result, researchers will continue to extend their understanding of how the reading processes function in the brain. Reading theories can serve as guidance for researchers to develop computerized models to test their findings. In education, science needs to interact with the practical. Research outcomes need a practical application if teachers are to use them to improve reading instruction for children. By the same token, education needs science to inform the psychology of teaching. By better understanding how the brain works and how instruction can change the brain, teachers can be more confident, consistent, and competent in using instructional strategies to enhance learning.

Implications for Future Research

Previously and recently published studies have incorporated reading tasks that require subjects to read short words, pseudowords or do other brief reading tasks. Future studies should incorporate longer reading tasks in order to observe more complex brain behaviors. The duration of the experimental treatment was sometimes just 3 weeks (Richards et al., 2000, 2002). Although the longest study was two years (Berninger et al., 2013), many of them were less than 60 days. We need studies that are more long-term in order to assess the rate of growth in a more natural timeframe. Early diagnosis of dyslexia and other reading disabilities is key to remediation that normalizes brain functioning. Neuroimaging could be used for early diagnosis of reading disabilities. There may come a time when neuroimaging can help guide educators in designing their instruction for a particular type of disability. Further studies linked with practical interventions could help educators determine the most effective intervention strategies based on brain strengths and weaknesses.

Limitations

This literature review was designed to provide an overview of theory and practicality as they relate to cognitive neuroscience and reading. Therefore, it is necessarily brief in its description of the brain, its function, and the specifics of the studies discussed. The reader is invited to explore the articles of interest listed in the reference section in depth.

Table 1. Comparison of Brain Activity in Typically Developing and Dyslexic/LD Readers

Study	Typically Developing Readers	Dyslexic/LD Readers
Shaywitz & Shaywitz, 2006; Pugh et al., 2013; Gebauer et al., 2012	Greater activation primarily in LH sites (inferior frontal, superior temporal, parietal-temporal, and middle temporal-middle occipital gyri)	Older readers engaged the left and right inferior frontal gyrus.
Shaywitz & Shaywitz, 2006; Pugh et al., 2013	RH sites (anterior site around the inferior frontal gyrus, parietal-temporal region, occipital-temporal region	Greater brain activation in the RH occipital-temporal region
Shaywitz & Shaywitz, 2006; Koyama et al., 2013	Connectivity between the left occipital-temporal seed region and the left inferior frontal gyrus, an area associated with language	Functional connectivity between the left occipital-temporal seed region and the right prefrontal areas associated with working memory and memory retrieval
Shaywitz & Shaywitz, 2007; Pugh et al., 2013		Greater activation in the anterior regions, less in the posterior regions in older individuals
Oldegard et al., 2008		Treatment non-responders: increased activation in the right middle temporal lobe

Table 2. Comparison of treatment and posttest changes summarizing Berninger et al. (2013)

Treatment Group A	Both	Treatment Group B
Step 1 gpc in the reading direction	Integrated reading and writing activities throughout	Step 1 gpc in the reading direction
Step 2 gpc for spelling and oral reading		Step 2 gpc for oral reading and phonological awareness
Step 3 orthographic strategies for written spelling and computerized rapid accelerated reading program (RAP)		Step 3 continue with above
Step 4 morphological strategies and RAP		Step 4 introduce orthographic strategies for written spelling
	Significant Posttest Changes	
Improvement in real word spelling		Improvement in real word spelling
Improvement in pseudoword spelling		--
Reading rate increased more significantly for Group A		Reading rate increased

Note: gpc = grapheme-phoneme correspondence. The primary differences in Treatment A, which resulted in greater achievement, were that gpc was taught through both reading and spelling, and morphology strategies were taught.

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