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ERPs While Judging Meaningfulness of Sentences with and without Homonym or Morpheme Spelling Foils: Comparing 4th to 9th Graders with and without Spelling Disabilities

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Abstract

Thirteen students with and twelve students without spelling disabilities judged whether sentences (1/3 all correct spellings, 1/3 with homonym foil, 1/3 with morpheme foil) were meaningful while event-related potentials (ERPs) were measured with EGI Geodesic EEG System 300 (128-channel hydro-cell nets). For N400, Rapid Automatic Switching (RAS) correlated with comprehending sentences with homonym foils in control group but with morpheme foils in SLD group. For P600, dictated spelling correlated with comprehending sentences with morpheme foils in the control group but solving anagrams with homonym foils in the SLD group. Educational significance and neuropsychological significance of these contrasting results are discussed.

Much research on literacy has focused on learning to read single words—real words or pseudowords (pronounceable but without meaning)—orally with accuracy and fluency (Strecker, Roser, & Martinez, 1998). However, beginning in the upper elementary school grades (4 and above in US schools) most reading instruction and written assignments require silent reading for texts across the content areas of the curriculum. Relatively little research attention has focused on the role of written word spelling in silent reading comprehension. Yet, word-specific spelling (a specific sequence of written letters corresponding to a specific spoken word with associated morphology and semantics), which is impaired in dysgraphia and dyslexia (Berninger, Richards, & Abbott, 2015), may affect silent reading comprehension as well as written composition.

It is also the case that research on specific learning disabilities (SLDs) has tended to focus on reading disabilities even though not all SLDs involve reading disabilities (Silliman & Berninger, 2011; Silliman & Mody, 2008) and not all reading disabilities are the same (Catts, Adlof, Hogan, & Ellis Weismer, 2005; Catts, Bridges, Little, & Tomblin, 2008). For

example, dysgraphia (impaired handwriting) may interfere with typical spelling development in individuals who have no oral reading disabilities (Berninger et al., 2015; Richards et al., 2015). Dyslexia is not just a reading disability—it involves word spelling disability as well as word reading disability (Lefly, & Pennington, 1991). Oral and language learning disability (OWL LD) impairs listening comprehension, reading comprehension, oral expression and/or written expression and often reading and spelling real words which may or may not have affixes at the end or beginning of base words (Silliman & Mody, 2008). That is, each of the three SLDs—dysgraphia, dyslexia, and OWL LD— may share in common impaired word-specific spelling but for different reasons. Yet, little is known about how these spelling impairments may affect their sentence-level reading comprehension.

Thus, the overall goal of the current study was to investigate two contrasting kinds of spelling errors in written sentences that could interfere with sentence reading comprehension. The first was homonym foils which are errors related to word-specific spellings (Ehri, 1980; Olson, Forsberg, Wise, & Rack, 1994). A written word appears in a sentence which when pronounced sounds like a real word but is not spelled correctly for the morphology and semantics of a word associated with that pronunciation. The second was morpheme foils, which are errors for the syntactic context in which they occur; an affix added to a base word to transform its grammar related to tense or number (inflectional suffixes) or part of speech (derivational suffixes) renders the syntax of the sentence ungrammatical. Of interest was whether students with and without SLDs impairing spelling have related sentence reading comprehension problems related to either homonym or morphology spelling errors. For reasons discussed next ERP methodology was used to test the hypothesis that they would and investigate the effect of spelling foils in a sentence reading comprehension in students with and without spelling disabilities in the upper elementary and middle school grades (middle childhood and early adolescence).

Relevance of ERP Methodology

MRI and fMRI studies have provided valuable information on the spatial locations of brain activity, for example, during text level reading comprehension (e.g., Buch, Mason, Meschyvan, Keller, & Just, 2014) and during phonological, orthographic, and morphological coding of words (Richards et al., 2006). DTI studies of white matter integrity inform which spatial locations are connected, and fMRI functional connectivity informs which spatial locations of the grey matter activate at the same moment of time in reference to a seed point from which connections originate (Richards et al., 2015). However, ERP (Event-Related Potential) studies show how brain events unfold over time (Carreiras & Clifton, 2004; Molfese, Molfese, & Kelly, 2001; Osterhout, 2000) and may shed insight into whether there are timing differences in processing the orthographic and morphological cues in written word spellings during reading comprehension in students with and without SLDs impairing spelling during middle childhood and early adolescence.

Pioneering studies showed that Auditory Evoked Potentials (EPs) at birth in 186 full-term newborns predicted their oral language development at age three (Molfese & Molfese, 1985) and their reading (normal, poor, dyslexia) and Verbal IQ (low, average, or high) at age eight (Molfese, 2000). Both good and poor readers were reading at their expected level based on

verbal reasoning, but those with dyslexia were reading significantly below their expected level based on verbal reasoning. In contrast, of interest in the current study was comparison of children with and without SLDs at a later stage of literacy acquisition (grades 4 to 9 when ages 9 to 14) with or without persisting word-specific spelling problems that may interfere with reading comprehension of written sentences and may be differentially associated with ERP components defined on basis of time elapsed from stimulus presentation and amplitude of recorded electrophysical activity.

Such sentence-level meaning processing draws on both linguistic cues in single words (Osterhout, Allen, & McLaughlin, 2002) and cognitive world knowledge (Hagoort, Hald, Bastiaansen, & Peterson, 2004; Mason & Just, 2011) and semantics or vocabulary meaning (Stahl & Nagy, 2005). One linguistic cue is word-specific spelling, which is a sequence of letters corresponding to a correctly spelled word which when pronounced sounds like a meaningful word for the sentence context (Davis et al., 2004). Another linguistic cue is morphology, which determines whether an affixed word grammatically fits the sentence syntax (Davis, Meunier, & Marslen-Wilson, 2004). If the affixed word does not fit, the sentence is not meaningful because of the morpheme foils (e.g., Allen, Badecker, & Osterhout, 2003). As shown by Bozic, Marslen-Wilson, Stamatakis, Davis, and Tyler (2007), who compared priming when morphological form and semantic meaning did and did not overlap in event-related analyses, morphological effects for form and meaning occur separately for derived words.

That is, morphology and semantics are not the same (Bozic et al., 2007; Stahl & Nagy, 2005), and making a judgment about whether a sentence is meaningful requires more than semantics alone; also required is processing the morphological cues some words may have (Stahl & Nagy, 2005). Indeed, homographs are not the same as homonyms. Simpson and Krueger (1991)'s ERP study with written sentences showed that the time course for processing ambiguous homographs (words with the same spelling but different meaning, such as *calf*, the body part, versus *calf*, the animal) in sentence context is different than for sentences without ambiguous homographs. In contrast to electrophysiological studies that have focused on the semantic processing of words in sentences (e.g., Neville, Nicole, Barss, Forster, & Garrett, 1991; Simos, Basile, and Papanicolaou, 1997; Noguchi, Takeuchi, & Sakai, 2002; Halgren et al., 2002) and found associations with N400, in the current study with children as participants, the focus was on morphology of written words.

To summarize, in the current ERP study, the detection of spelling anomalies (due to homonym foils or due to morpheme foils) was studied in written sentences. Although considerable fMRI studies have focused on word-level reading (for review, see Palmer, 2004) or sentence-level reading (for review, see Caplan, 2004), the current ERP study focused on the timing of the integration of word-level and syntax-level in the judgment of written sentence meaning.

Prior Research on Sentence Reading in Children and Adolescents with and without SLDs

Both ERP (Shulz et al. 2008), and fMRI (Meyler et al., 2007) research with children and adolescents (Kronbichler et al., 2006) has shown how those with and without SLDs differ in reading comprehension processes. For example, semantic processing is typically characterized by activation in left-hemispheric regions of the inferior frontal and superior temporal cortex and by an electrophysiological N400 effect between 240 and 540 milliseconds; but Shulz et al (2008) showed that children with dyslexia exhibited not only the N400 effect but also decreased BOLD activation for sentence reading in inferior parietal and frontal regions, and for semantic processing in inferior parietal regions. They suggested that inferior frontal regions are specific to syntactic processing and that in children with dyslexia the semantic impairment during sentence reading reduces the response in left anterior brain regions which underlies the N400 effect. However, Casalis, Colé, and Sopo (2004) showed that individuals with developmental dyslexia may also have impaired morphological awareness, which is related to how affixes transform base words in regard to tense, number, and part of speech, and is not the same as semantic meaning.

Theoretical Framework

Considerable research has now shown that multiple working memory components supporting language learning and its use contribute to processing language at multiple levels—subword, word, syntax, and text levels of language (e.g., Berninger & Richards, 2010). Thus, in the current study, two levels of language—lexical or word level and syntax or sentence level—were taken into account in designing the behavioral assessments given before collecting ERPs and the tasks used during recording of ERPs.

Research Aims

One research aim of this study was therefore to use EEG to measure ERPs during three contrasting sentence tasks designed to identify possible differences in sentence reading comprehension between a control group and a group with specific learning disabilities (SLDs) impairing spelling. A second aim was to correlate the ERP signals with behavioral measures shown in past research to support language learning, which differ between those with and without SLDs.

Method

Behavioral Measures Administered Prior to ERP Collection

A test battery was first administered to determine whether students in grades 4 to 9, whose parents learned about the study through flyers distributed to local schools, met research criteria for a spelling disability (SLD group) or for typical reader and speller (control group).

Cognitive-oral language translation—The *Wechsler Intelligence Scale for Children, 4th Edition (WISC IV)* (Wechsler, 2003) *Similarities, Vocabulary, and Comprehension* subtests (test-retest reliability 0.93 to 0.95) were administered. These subtests require

translation of oral language into single words, word phrases, single clauses, or multiple clauses. Raw scores were converted to scaled scores, which were combined to obtain a standard score ($M=100$, $SD=15$) for the *WISC IV Verbal Comprehension Index*. If the prospective participant scored in the normal range (at or above a standard score of 80 or -1 and $1/3$ SD), the criterion for participation was met for the translation measure. However, only the Vocabulary subtest score, an indicator of semantic processing, is reported in Table 1 and used in the correlational analyses with N400 and P600.

Working memory components for coding three word forms—To assess *phonological storage and processing*, the *Comprehensive Test of Phonological Processing (CTOPP)* (Wagner, Torgesen, & Rashotte, 1999) *Nonword Repetition* (test-retest reliability 0.70) was given. The task is to listen to an audio recording of nonwords pronounced one at a time and then repeat exactly the heard oral nonword, which contains English sounds but has no meaning. It requires analyzing and synthesizing subword sounds into word units. The raw scores are converted to standard scores for age ($M=100$, $SD=15$).

To assess orthographic storage and processing, *The Test of Orthographic Competence (TOC)* (Mather, Roberts, Hammill, & Allen, 2008) *Word Scrambles* subtest (test-retest reliability 0.88 to 0.90) was given. The task is to rearrange letters (subword level) in a scrambled word to create a correctly spelled real word (word-specific spelling at word level in which letter identity, position and sequence conform to English orthotactics).

To assess storage and processing of the morphological word form (base and affixes) in heard and read language, the experimenter-designed *Comes-From Task* was given for judging whether or not a word is derived from a base word (Nagy, Berninger, & Abbott, 2006) which has been used in both a multi-generational family genetics research study of dyslexia and a longitudinal study of typically developing readers and writers. Examples from this measure include the following which share a common spelling unit—er—but only in the second example does that spelling unit function as a morpheme that transforms a verb into a noun: Does *corner* come from *corn*? Does *builder* come from *build*? Raw scores are transformed to z-scores ($M=0$, $SD=1$) based on research norms (Nagy et al., 2006).

Working memory component for supervisory switching attention—*Rapid Automatic Switching (RAS)—Letters and Numerals* (test-retest reliability 0.90) (Wolf & Denckla, 2005) was given. The task is to name alternating lower case printed letters and written numerals arranged in rows. The score is the time required to name all the alternating letters and numerals in all the rows, which is converted to a standard score ($M=100$ and $SD=15$).

Word-level and sentence- and text-level reading skills—Because most reading in fourth grade and above is silent, a measure of silent word reading fluency was administered. The *Test of Silent Word Reading Fluency (TOSWRF)* (test-retest reliability is .92) (Mather, Hammill, Allen, & Roberts, 2004) was given which requires the reader to mark the boundaries for word-specific spellings in a series of letters arranged in rows. The score is the number of correctly detected and marked word boundaries in 3 minutes. Raw scores are converted to standard scores for age ($M=100$, $SD=15$). In addition, a measure drawing on

both sentence and text level reading comprehension was given. The task on the *WJ III Psychoeducational Battery* (Woodcock et al., 2001b) *Passage Comprehension* (test-retest reliability is .85) is to supply orally a missing word in the blank that fits the accumulating context of the sentence and preceding text. The raw scores are converted to standard scores ($M=100$, $SD=15$).

Qualifying for participation in the study—If the prospective participant had a history of spelling problems and met research criteria on the following measures of word-specific spelling (either below $-2/3$ SD (25th %tile) or below the population mean and at least one standard deviation below Verbal Reasoning Index, both of which are evidence-based criteria for spelling disability (Berninger & Richards, 2010), the individual qualified for participation in the study in the SLD group. If the prospective participant had no history of spelling problems and did not meet the either the low achieving ($-2/3$ SD) or discrepancy (below population mean and Verbal Comprehension Index) criterion for at least two of the spelling disability measures, then the individual qualified for the control group.

Word-level word-specific spelling underlying detection of correct word-specific spelling in homonym foils—The *TOC Homophone Choice (ages 9 to 12)* or *Word Choice (ages 13 to 16)* (test-retest reliability .72 to .75) was given for which the task is to identify a correct spelling for a specific word. Regardless of age of the child, the raw scores were transformed into scaled scores ($M=10$, $SD=3$).

Word-level word-specific written spelling of dictated real words—*Wechsler Individual Achievement Test, 3rd Edition (WIAT III) Spelling* (Pearson, 2009) (test retest reliability .92) was also given on which the task is to spell in writing dictated word-specific spellings for real words, pronounced alone, then in a sentence, and then alone. The score is a standard score ($M=100$, $SD=15$).

Participants

Those that met the criteria for the SLD group or control group were invited to participate in the ERP study. Those whose parents granted informed consent and the participating child granted assent, per the institutional review board's approved procedures for research with human participants, were scheduled for a session where ERPs were collected. Altogether 25 participants were assigned to diagnostic groups for this study: 12 controls without SLDs ($n=5$ females, 7 males; 9 right handed, 3 left handed) and 13 with SLDs ($n=5$ females, 8 males; 7 right handed, 5 left handed). Mean age was 11.9 years ($SD=1.6$). Most were in upper elementary or middle school grades 4 to 7 (70.8%). All were European American by self-report except for five controls who reported mixed racial identity (1 European American/Native American; 3 Native American/Asian American; and 1 European American/Hispanic). Almost all the parents were college graduates (83.4% of the mothers and 68.4% of the fathers).

ERP Procedures

Stimuli and tasks—30 Correct Sentence (CS) items, 30 sentences with homonym foil errors (HFE) items, and 30 sentences with morphology foil errors (MFE) items were

presented one word at a time. Each sentence contained one critical word yoked across sentences that rendered the sentence meaningful or not meaningful. Each trial commenced with the onset of the critical word and concluded 1100 msec later, at the onset of the subsequent word. Examples of stimuli follow for a correct sentence with all words correctly spelled and an incorrect sentence with one homonym foil (sounds like a word that could make sense but is misspelled), and an incorrect sentence with one morphological foil (stem makes sense but affix error does not fit sentence syntax), respectively: 1. Her job was easy most of the time at first. 2. Bradley prefers cats over dawgs because they purr. 3. After dinner he washed his hands with soaped and water. The three kinds of sentences (CS, SPE, and SYE) were presented in random order. The task was to press a key for a yes (the sentence is meaningful) or no (the sentence is not meaningful) response.

ERP methods—Scalp potentials were collected using an EGI Geodesic EEG System 300 with 128-channel hydro-cell nets. Sensor impedances were maintained below 50 kOhms. Data were sampled at 250 Hz and bandpass filtered offline between 0.5 and 49 Hz. Data from Bad channels or channels with flat-lined or flailing traces were replaced with spatially weighted average of data from neighboring channels using vendor supplied software (NetStation, EGI Inc., Eugene, OR).

Participants viewed sequences of single words presented in the center of an LCD display. Software written in Presentation Programming Language controlled the stimulus display and delivered digital markers identifying the stimulus category into the EEG recording concurrently with the onset of each stimulus trial. For the sentence task, word duration was 280 msec, and intervals between words were 570 msec. Sentences were followed by a question displayed on screen about the meaningfulness of the preceding sentence. A yes or no response to this question via button press initiated display of the next sentence sequence. In each participant's recording, the digital markers were used to locate and extract scalp potential sequences corresponding to each stimulus trial. Initial offsets at the beginning of each trial were corrected to a common baseline by subtracting the mean potential from the 100 msec preceding trial onset. Trials exhibiting deflections greater than 50 microvolts were deemed to contain artifact and were discarded. The remaining trials were averaged for each stimulus category. ERP components were estimated using average of Cz sensor (standard 10–20 EEG system for electrode placement) and the immediately neighboring sensors (excluding those designated as bad), referenced to the left mastoid sensor (Allen et al., 2003). N400 components in ERP trials were estimated from mean of potential between 300 to 500 msec; P600 components were estimated from 500 to 800 msec. These stimulus category channel averages from the individual participants were averaged again to obtain stimulus category averages for the entire group of participants.

ANOVAs were used to compare the EEG amplitude between groups of participants; and individual correlations were computed to correlate the behavioral scores with EEG amplitudes using SPSS software. All 12 of the control group, but only 12 of the SLD group had usable ERP data for all the analyses.

Data Analyses

Descriptive statistics were computed for the behavioral measures, for the ERP responses for the correct sentences, and for the ERP responses for the incorrect sentences. Inferential statistics compared accuracy and RT for correct sentences, for different kinds of spelling errors on incorrect sentences, and for differences between the control group and SLD group in accuracy and reaction time for these sentences without and with spelling foils. First, ANOVA was used to test for significant main effects for group and then *t*-tests were used for posthoc comparisons for the main effects for which *F*-values for main effects were significant. Finally, behavioral measures were correlated with N400 and P600 for different kinds of spelling foil errors in incorrect sentences separately for the control group and for the SLD group. Only results for significant behavioral-ERP correlations are reported.

Results

Descriptive Statistics

See Table 1 for the descriptive statistics (means and standard deviations) for the behavioral measures administered before the ERPs were collected. Not surprisingly, the control group scored higher on average on these measures, which were used in assigning participants to either control or SLD groups. See Table 2 for the descriptive statistics (means and standard deviations) for percent accuracy and reaction time in milliseconds for correct responses on sentences without and with specific kinds of spelling foils. See Table 3 for the same descriptive statistics for accuracy and reaction time for incorrect responses of sentences without and with specific kinds of spelling foils.

Correct and Incorrect Judgments on Correct and Incorrect Sentences

Correct sentence judgments—For correct sentence judgments, there were no significant group differences for percent correct, $F(1,23) = 0.51$, $p = 0.48$ or reaction time, $F(1,23) = 0.05$, $p = 0.82$ for correct sentences with no spelling foils interfering with sentence meaning. For sentences with spelling foils interfering with sentence meaning, there was a significant group difference for accuracy, $F(1,23) = 5.45$, $p = 0.03$, but not for reaction time, $F(1,23) = 0.74$, $p = 0.40$. As shown in Table 2, for correct responses the control group was always more accurate than the SLD group whether the incorrect sentences had a homonym or morphology foil.

Incorrect sentence judgments—For incorrect responses, on the correct sentences without spelling errors, the control and SLD group did not differ in accuracy $t(23) = 0.72$, $p = 0.48$, but on the incorrect sentences with spelling errors, the control group was significantly more accurate than the SLD group $t(23) = 2.33$, $p = 0.03$. On sentences with morphological foils, the control group was significantly more accurate than the SLD group $t(23) = 4.52$, $p = 0.001$. There was a significant group difference in reaction time for correct sentences without spelling foils, $F(1,23) = 8.44$, $p = 0.0008$, but not for incorrect sentences with homonym foils, $F(1,23) = 1.68$, $p = 0.21$, or morpheme foils, $F(1,23) = 1.12$, $p = 0.30$. As shown in Table 3, the control group spent more time processing the sentences than did the SLD group, which might account for the greater accuracy of the control group. Although the same pattern for means was observed for sentences with and without spelling foils, the

large standard deviation for the control group may have rendered a nonsignificant overall result for sentence type.

ERP Results

Figure 1 shows example waveforms for the three different sentence types for the control group. Figure 2 shows the example waveforms for the three different sentence types for the SLD group.

Correlations between Behavioral Measures and ERPs for Control Group

N400—A significant correlation was found for *Wolf and Denckla RAS* (switching attention) and N400 on sentences with homonym foil spelling errors, $r = 0.798$, $p = 0.006$. The correlation was positive, so the higher the score on attention switching, the larger the amplitude for this N400 signal.

P600—The *Test of Silent Word Reading Fluency* (TOSWRF) significantly correlated with P600 during judgments for incorrect sentences with homonym foil spelling errors, $r = -.69$, $p = .014$.

Correlations between Behavioral Measures and ERPs for SLD Group

N400—*Wolf and Denckla RAS* (Rapid Automatic Switching) correlated with N400 during judgments for incorrect sentences with morphological foil spelling errors, $r = .65$, $p = 0.05$. See Table 4.

P600—The *WIAT 3 Spelling* correlated with the P600 signal during sentence judgement for incorrect sentences with morphological foils, $r = -.65$, $p = .022$. In addition, *TOC Word Scrambles* (anagrams) subtest was positively correlated with P600 during sentence judgments for sentences with homonym foils, $r = 0.604$, $p = 0.049$. See Table 5.

Differences between Groups in Behavioral-ERP Correlations

There was a significant difference between the mean correlation values between RAS and N400 for the control group and the same correlation for the LD group (LD group $r = 0.28$) (difference in correlation p value, 0.0427). Figure 3 shows the regression lines for the two groups for this correlation plotted on the same graph.

Discussion

Neurological Significance for Sentence Reading Comprehension

Correct versus incorrect responses—The control and SLD groups did not differ significantly in accuracy or RT for silent sentence reading comprehension for correct sentences without spelling foils. When sentences did have spelling foils, analysis of correct responses showed the control group was more accurate than the SLD group. However, analysis of the incorrect responses showed that the control group was less inaccurate than the SLD group, especially at detecting morphological foils. The control group spent more time processing sentences with spelling foils, which may explain, at least in part, why they

were more likely to detect the spelling foils and make an accurate sentence meaning judgment.

N400—For the N400, RAS correlated significantly with incorrect sentences with homonym foils in the control group but not in the SLD group. The difference between the control group and SLD group was statistically significant for the correlation with homonym foils. This finding suggests that the group without SLDs in spelling but not the group with SLDs in spelling can detect homonym foils (attend to word-level spelling errors independent of syntax-level context in which they occur) because they have the supervisory attention for switching attention across the sequential letters and graphemes in the written words that differentiate meaningful and non-meaningful sentences and across the accumulating serially ordered words in the sentence syntax that conveys meaning. This finding also suggests that N400 may be related to orthographic coding in word-specific spelling and not just semantics, as found in prior ERP studies (e.g., Neville et al., 1991; Simos et al., 1997; Noguchi et al., 2002; Halgren et al., 2002).

At the same time, the N400 was not correlated with *WISC 4 Vocabulary* in either the SLD or control group, but was correlated with sentences with morphological foils in the SLD group, providing additional evidence that morphology and semantics are not identical processes. Further research is needed to determine whether the finding that RAS was correlated with detecting morphological errors in the SLD group but not the control group is related to individuals with spelling disability having difficulty attending to morphemes and thus identifying morpheme foils. That finding plus the lack of significant correlation between *CTOPP Nonword Repetition* and N400 in either group suggests that phonological coding may not be as relevant as morphological coding (SLD group) or orthographic coding (control group) during silent sentence reading in grades 4 to 9. However, collectively the findings suggest that RAS is associated with N400 ERPs in both groups but with a different kind of spelling foil—orthographic in the case of the control group and morphological in the case of the SLD group.

P600—For the control group this ERP signal was associated with silent word reading fluency and meaning judgments for sentences with homonym foils. For the SLD group, in contrast, this ERP was significantly associated with *TOC Word Scrambles* and meaning judgments for sentences with homonym foils. So P600 may be associated with detection of homonym foils but the control and SLD groups may draw on different linguistic cues in doing so. The silent word reading fluency measure is more sensitive to identifying word specific spellings corresponding to orthography, phonology, morphology, and semantics whereas *TOC Word Scrambles* is more sensitive to the orthotactics—permissible letter sequences in word-specific spellings. However, production of dictated spellings was associated with P600 during meaning judgements for sentences with morphological foil spelling errors. This finding is consistent with the importance of morphology, not just alphabetic principle, in spelling dictated words.

Contributions of ERPs—Posner and McCandliss (1993) called attention to the value of using multiple tools for study of the brain and cautioned that conclusions about time and spatial location may depend on the brain imaging tool used. In the long run, ERPs, when

used in conjunction with other imaging tools, may support the discovery of the space-time units in human brain that Weiss and Weiss (2003) envisioned. Until then, the current results for developing readers with and without spelling disabilities inform the temporal course of processing sentence meaning when homonym foils or affixed foils affecting sentence level reading comprehension occur in unpredictable locations in the sentence and not just at the final word position in a sentence.

Educational and Translation Neuroscience Significance

Of note, the behavioral measure of passage reading comprehension that requires processing of sentences and text was not correlated with either the N400 or P600. Yet, measures of supervisory attention, word-specific spelling, word scramble, and silent word reading fluency were correlated with sentence level reading comprehension. Both reading assessments and instruction should focus on sentence level reading comprehension and not just text-level passage comprehension for both those with and without SLDs impairing word-specific spelling underlying both reading and writing.

The difference between the control group and the SLD group in the correlations between Wolf and Denckla *RAS* (switching attention) and reading sentences with spelling errors (shown in Figure 3) on N400 (a) converges with behavioral findings showing the relationship between *RAS* and switching attention to changing units of written language within and across words (Berninger, Abbott, Cook, & Nagy, 2016); and (b) has implications for the supervisory attention of working memory during sentence reading comprehension. Ability to switch attention from letter to letter in sequence within a written word and then across the sequential words in sentence syntax likely plays an important role in learning to read. Instructional strategies that can be used to teach decoding with sequential graphemes include the following: use alternating colors of graphemes in printed words used for teaching decoding or ask students to rewrite taught words in alternating colors for sequential graphemes. Color serves as a cue to signal switching attention across sequential letters in written words that has been used effectively in instructional research (see Berninger & Richards, 2010).

However, for the SLD group *RAS* was related to reading sentences with morphological foil errors, suggesting that those with spelling disabilities may be overly focused on grapheme-phoneme correspondences of alphabetic principle and not noticing the spelling units that function as morphemes. See Casalis et al. (2004) for the importance of teaching morphological awareness to students with reading and spelling disabilities. Students with SLDs in spelling benefit from explicit instruction in integrating morphology with orthographic-phonological correspondences (Richards et al., 2006) in reading or spelling English, which is a morphophonemic orthography.

In addition, in the SLD group *TOC Word Scrambles* (anagrams) was positively correlated with P600 during sentence judgments for incorrect sentences with homonym foil spelling errors. Orthotactic knowledge of letter identity and permissible positions and sequences of letters plays an important role in learning word-specific spellings. The correlation between phonological word form (nonword repetition) was not correlated with silent sentence reading comprehension for correct sentences or incorrect sentences with either homonym or

morpheme foil spelling errors. Again this finding shows the importance of explicit instruction in orthographic awareness and not just phonological awareness in remediating SLDs related to word reading or spelling (Richards et al., 2006).

Conclusion

ERPs are a useful tool for studying silent sentence reading comprehension in sentences with and without homonym foil or morpheme foil spelling errors in students in middle childhood and early adolescence with and without spelling disabilities. Orthographic coding in working memory appears to be more sensitive than phonological coding in working memory to ERP signals during silent sentence reading comprehension at this developmental level—middle childhood and early adolescence—for both those with and without spelling disabilities. The brain lesson from this ERP study is that instruction in orthographic coding beyond grapheme-phoneme correspondence and morphological coding needs to be added to phonological coding in literacy instruction across the content areas in the upper elementary and middle school grades.

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Figure 1. Averaged ERP wave forms for typical readers for sentences without or with one of two kinds of spelling errors 1) blue line – no error in sentence 2) green line – homonym foil spelling error in sentence; 3) red line – morpheme foil spelling error in sentence.

Figure 2.

Averaged ERP wave forms for SLDs in spelling for three different sentences types 1) blue line – no error in sentence 2) green line – homonym foil spelling error in sentence; 3) red line – morpheme foil spelling error in sentence.

Figure 3.

Comparison of the Control group with the Specific Learning Disability group with spelling disability for the correlation of the N400 signal in microvolt units with the RAS score, which was normalized to a standard score of 100 with an SD of 15 for both groups. The control group correlation had an r^2 value of 0.636, while the SLD group had an r^2 value of 0.078.

Table 1

Mean (M) and Standard Deviation (SD) for Behavioral Measures in Control and SLD Groups

	Control M (SD) (N=12)	SLD M (SD) (N=13)
<i>WISC 4 vocabulary</i>	12.83 (2.66)	11.85 (3.00)
<i>TOC Homophone/Word Choice</i>	11.67 (1.53)	10.33 (2.17)
<i>WIAT III Spelling</i>	109.75 (14.34)	87.23 (10.48)
<i>TOWSWRF</i>	98.17 (10.14)	92.08 (8.21)
<i>WJ III Passage Comprehension</i>	103.00 (10.24)	96.54 (11.33)
<i>CTOPP</i> Phonological Word Form	8.36 (2.50)	7.85 (1.46)
TOC Orthographic Word Form	10.00 (2.83)	8.50 (2.02)
Morphological Word Form	.42 (.33)	.07 (.39)
<i>Wolf & Denckla RAS</i>	106.00 (10.12)	96.25 (10.21)

Note. Phonological Word Form is CTOPP Nonword Repetition. Orthographic Word Form is TOC Word Scrambles. Morphological Word Form is research version of Comes From.

Table 2

Means and Standard Deviation (SD) for Accuracy and Reaction Times for Correct Responses during Silent Reading Judgments of Sentence Meaning for Sentences without and with Two Kinds of Spelling Foils.

	Control (N=12)		SLD (N=12)	
	Mean	SD	Mean	SD
Correct Sentences— No Foils				
Proportion Correct	0.84	0.23	0.78	0.19
Reaction Time	2,440	1,780	2,300	1,180
Incorrect Sentences with Homonym Foils				
Proportion Correct	0.83	0.19	0.63	0.22
Reaction Time	1,570	710	3,260	6,750
Incorrect Sentences with Morpheme Foils				
Proportion Correct	0.89	0.07	0.50	0.29
Reaction Time	2,330	1,370	2,470	1,320

Table 3

Means and Standard Deviation (SD) for Accuracy and Reaction Times for Incorrect Responses (1-Proportion Accurate) during Silent Reading Judgments of Sentence Meaning for Sentences without and with Two Kinds of Spelling Foils.

	Control (N=12)		SLD (N=12)	
	Mean	SD	Mean	SD
Correct Sentence				
Accuracy	0.84	0.23	0.78	0.19
Reaction Time	3,520	2,020	1,700	780
Incorrect Sentence with Homonym Foil				
Accuracy	0.83	0.19	0.63	0.22
Reaction Time	4,720	7,970	1,840	820
Incorrect Sentence with Morpheme Foil				
Accuracy	0.89	0.07	0.50	0.29
Reaction Time	3,480	2,850	2,570	1,140

N400 Descriptive Statistics (Means and Standard Deviations) and Comparison of Conditions for Students with and without Specific Learning Disabilities (SLDs) in Spelling. See text for description of sentences tasks that do or do not have spelling errors of two types—homonym foils or morpheme foils and for results of t-tests and p-values.

Table 4

SENTENCE TASKS							
	Correct Sentences (CS)	Sentences with Homonym Foils		Sentences with Morpheme Foils		N	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>		
Group							
Control	12	-1.24	3.51	-1.41	4.14	-1.95	3.83
SLD	12	-3.30	3.90	-6.45	4.08	-5.20	3.73

P600 Descriptive Statistics (Means and Standard Deviations) and Comparison of Conditions for Students with Specific Learning Disabilities (SLDs) in Spelling or Typical Language Learners without SLDs. See text for description of sentences tasks that do or do not have homonym foils or morpheme foils and for results of t-tests and p-values.

Table 5

SENTENCE TASKS							
	Correct Sentences (CS)	Sentences with Homonym Foils		Sentences with Morpheme Foils		N	
		<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>		<u>M</u>
Group							
Control	12	0.76	3.68	1.05	4.78	1.30	3.55
SLD	12	-.93	1.56	-2.62	2.95	-3.37	2.71