RESEARCH RESULTS

System 44™ Neurocognitive Intervention Study

PROFILE

SAMPLE:
New York City public and private school students aged 10-12 years, identified as striving readers or as having a learning disability with impairment in reading

GRADES:
4–7

STUDY DESIGN:
Promising (ESSA)

EVALUATION PERIOD:
2018-2019 school year

IMPLEMENTATION:
Afterschool program, 3 times a week

MEASURES:

- N170 Event-Related Potential
- *Reading Inventory*
- *Phonics Inventory*
- Orthographic Choice Task
- Homophone Choice Task
- WISC-V Digit Span Subtest
- WRMT-R Word Identification & Word Attack Subtests
- CTOPP-2 Elision, Word Blending, Phonemic Isolation, Digit & Letter Rapid Naming Subtests
- TOWRE-2: Sight Word Efficiency and Phonemic Decoding Efficiency Subtests

THE CHALLENGE

Learning to read requires the development of phonological awareness and phonemic awareness, acquisition of the orthographic patterns for words and their corresponding sounds, as well as semantic information (Saha et al., 2019). Accumulating evidence from randomized controlled trials demonstrates that, with appropriate intervention, reading and spelling difficulties can be remediated (Galuschka et al., 2014). Such findings emphasize the importance of providing evidence-based interventions to students.

However, questions remain regarding what type of intervention is appropriate at what age and level of skill development, as well as what intensity and duration of instruction may be efficacious. Investigations of such questions are central to the domain of Educational Neuroscience, which in the case of reading aims to understand what neuronal signatures underlie developmental milestones of specific reading skills.

Decades of neuroimaging studies have provided insight into how the brain develops the neural networks that support reading (Dehaene et al., 2010). Studies have identified the areas of the brain that are activated when students with and without reading disabilities read text (Price, 2012; Pugh et al., 2000). Other studies have added to our understanding of differences in the processing of text between developing and skilled readers (Martin et al., 2015). Such work has helped us to understand that the brain did not evolve to read, but that when provided with the appropriate experiences and explicit learning inputs, it will establish a reading system (Draganski et al., 2004). Development of the brain's reading network is an intricate and lengthy process (Dehaene et al., 2010; Maurer et al., 2005). Changes to connections and patterns of activation between neuron assemblies and neural systems underlie both learning and development. Neuroimaging techniques have been helpful in exploring the complex interworking of the many sensory and cognitive systems engaged when reading.

Reading is a linguistic process that unfolds extremely rapidly. The electroencephalographic (EEG) method operates on a millisecond level, meaning it is well-suited for studying complex sequences of processing like those involved in reading. Event-related potentials (ERPs), derived from the EEG recordings, are indices of brain activations associated with particular stages of information processing during sensory and cognitive processing, such as when reading (Luck, 2005).

An ERP component is typically depicted as a positive or negative peak deflection within a rendering of a waveform. ERPs are labeled with respect to the time of the deflection peak.

Study outcomes suggest that orthographic knowledge is a critical factor that interacts with phonemic skills during the development of the brain's reading network.

EEG studies have explored many aspects of the reading process as it unfolds (Brenitz et al., 2003; Coch & Benoit, 2015; Grainger & Holcomb, 2009; Van Berkum et al., 2005). The studies have identified various ERPs associated with distinct processing stages of reading. This HMH research inquiry is situated in this field of study with the specific aim to investigate the effects of the *System 44* reading intervention on a well-researched neurophysiological index associated with reading performance. The target ERP component for this study is referred to as the reading-related N170, which is a negative deflection in the waveform that peaks at approximately 200 milliseconds after the presentation of a stimulus, typically words and symbols.

The reading-related N170 ERP component has been used as an index of word automaticity and is thought to represent a specialization for print. Expert readers demonstrate a differential response to words in the left vs. right hemisphere of the occipito-temporal cortex (McCandliss et al., 2003; Maurer et al., 2008).

THE SOLUTION

One of the challenges for educators is to provide the quality and intensity of instruction that striving readers clearly benefit from. *System 44* was developed to support students in Grades 3 to 12 who are two or more years behind their peers in reading ability as assessed by the *Reading Inventory* and *Phonics Inventory*.

System 44 is a foundational program for mastering the 44 sounds and 26 letters that constitute the English language. *System 44* targets foundational skills such as phonemic awareness, phonics, vocabulary, fluency, and comprehension, thought to be critical for successful remediation (Foorman & Torgesen, 2001).

System 44 involves teacher-facilitated whole and small-group instruction, personalized technology, and independent reading. The instructional focus is on building decoding and phonological awareness skills using adaptive software. Targeted instruction, delivered systematically, over at least 60 sessions has revealed improvement in basic literacy skills that support fluency.

THE STUDY

The Neurocognition of Language Lab (NCLLab) at Teachers College, Columbia University uses EEG to investigate the relationship between ERPs and diverse linguistic and cognitive processes. Researchers at the NCLLab conducted a classic pretest-posttest educational research design to investigate the N170 ERP neural response to the *System 44* intervention program, and its correlation with standard performance measures of literacy achievement.

PARTICIPANTS

Participants were students in 4th, 5th, 6th, and 7th grade (aged 10-12 years), some typically developing and some who identified as striving readers or as having a learning disability with impairment in reading (dyslexia). There were 21 participants in total, 11 of whom identified as female and 10 as male, who took part in the *System 44* pre-/post-intervention study. The study included three groups: 1) typically developing advanced decoders (TDA, n = 7); 2) typically developing-developing decoders (TDD, n = 5); and 3) students with reading disabilities (SRD, n = 9). Age did not vary significantly between the three groups. Only students with reading disabilities (SRD, n = 9) were enrolled in the *System 44* intervention program.

RESEARCH QUESTIONS

The aim of this study was to examine potential amplitude and lateralization shifts in reading-related brain activation as indexed by the N170 ERP component, following participation in the *System 44* intervention program. Our research questions included:

1. Does *System 44* change the N170 for 4th, 5th, 6th, and 7th grade students (ages 10 to 12) who are identified as striving readers by parents and/or an individual educational plan (IEP) as well as categorized by the *Phonics Inventory* as pre-, beginning, or developing decoders?
2. Is there a relationship between students' reading ability (measured by the *Reading Inventory* and *Phonics Inventory*) and the amplitude or lateralization of the N170 component among students ages 10 to 12 (4th, 5th, 6th and 7th grades)?
3. How do the behavioral and neurophysiological responses of 4th, 5th, 6th, and 7th graders who participate in *System 44* compare with age-matched comparison groups, before and after intervention?
4. Based on possible sub-categories within each group that may present as data is collected, is there observable overlap and if so, how did their profiles shift over the course of the school year?

EXPERIMENTAL METHOD

Behavioral measures and neurophysiological data were collected at two time points: pre- and post-intervention, in the fall and spring of the 2018-2019 academic school year. The order of data collection was counterbalanced at both time points across participants

SYSTEM 44 IMPLEMENTATION

The *System 44* Intervention Study was implemented over the 2018-2019 academic school year. The goal of the study was to examine brain responses of a target group of students to the *System 44* intervention in comparison to grade level-matched typically developing readers and reading level-matched students. The *System 44* intervention was delivered by two certified reading teachers. The head instructor was responsible for identifying and preparing the small-group differentiated instruction based on student reports. The teaching assistant supervised students during independent reading activities and use of instructional technology. All three key elements of the *System 44* program were implemented, specifically:

- Small group instruction
- Self-paced adaptive technology with explicit systematic instruction that reinforces small group instruction. Each student had access to an iPad to facilitate engagement with the instructional technology.
- Independent reading, including print and online books.

The program was administered from December 2018 through April 2019 and delivered afterschool at Teachers College, Columbia University on Tuesdays, Wednesdays, and Thursdays from 3:45 to 4:45 pm.

READING ASSESSMENTS IMPLEMENTATION

The reading achievement measures were administered by a licensed neuropsychological evaluator. The evaluator conducted the first scoring of the assessments. A second scoring was completed by an experienced Speech-Language Pathologist. The assessment battery consisted of: *Reading Inventory*, *Phonics Inventory*, Orthographic Choice Task, Homophone Choice Task, Wechsler Intelligence Scale for Children (WISC-V) Digit Span subtest, Woodcock Reading Mastery Test - Revised (WRMT-R) Word Identification and Word Attack subtests, Comprehensive Test of Phonological Processing - Second Edition (CTOPP-2) Elision, Word Blending, Phonemic Isolation subtests and the Digit and Letter Rapid Naming subtests, Test of Word Reading Efficiency - Second Edition (TOWRE-2) Sight Word Efficiency and Phonemic Decoding Efficiency subtests.

EVENT-RELATED POTENTIAL BRAIN RESPONSES

Researchers at the NCLLab employed high-density EEG to record the brain responses of study participants and investigate the relevant research questions. EEG is a noninvasive brain imaging method that directly measures voltage fluctuations (electrical activity) generated by synchronized synaptic activity in populations of cortical neurons, specifically pyramidal cells. The electrical signal generated by synchronized synaptic activity travels through the brain and through the protective dura layers surrounding the brain as well as through the skull and scalp. The electrodes that capture the EEG signal are embedded in sponges soaked in an electrolyte solution that acts as a conductor allowing the signal to reach the electrode.

One hundred and twenty-eight electrodes are positioned across special nets fitted to a participant's head. A diagram of the EEG net is shown in Figure 1.

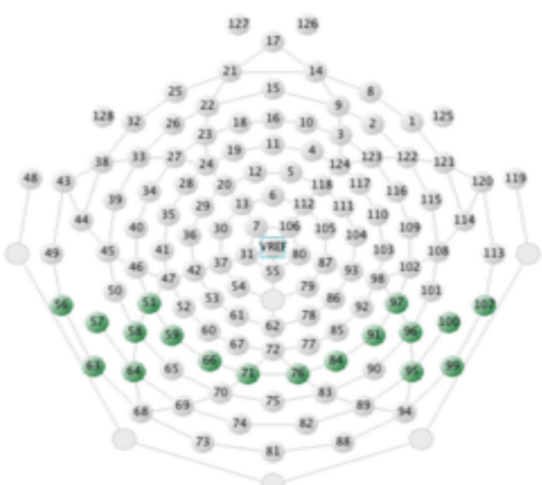


Figure 1. Diagram of the 128 channel Geodesic EEG Net with electrodes of interest highlighted in green.

The net permits the brain responses of study participants to be continuously sampled at millisecond rates. When recorded and processed, the EEG signal can provide information about patterns of brain responses associated with specific cognitive processes. Such patterns make up the ERPs. ERP components can describe the observed waveform or have a theoretical basis and are interpreted within the context of the research question to provide insights relating to perception, cognition, and motor functions. The experimental task used for the brain-imaging aspect of the study to explore the influences of the *System 44* intervention program on the specialization of visual association cortical areas thought to contribute to the automatic processing of written words was the one-back paradigm.

The stimuli for this study included 89 real words, each psycholinguistically matched (for complexity, length, frequency and imageability, among other measures). The stimuli were presented in three separate blocks (representing the Word Condition, Pseudoword Condition, Symbol Condition) that were counterbalanced to limit the effects of task novelty and participant fatigue. The experimental task carried out by participants, while EEG was being recorded, was a one-back paradigm requiring button-press responses whenever a repeated stimulus was detected. Accuracy and reaction time of responses to these tasks were recorded in addition to the brain responses. An example of the stimuli used to elicit the brain response is shown in Figure 2.

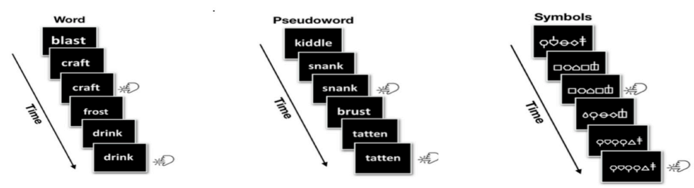


Figure 2. Example of separate condition blocks with indication of trials that would require a button press by the participant.

ANALYTIC METHODOLOGY

BEHAVIORAL ASSESSMENTS

For the neuropsychological measures that suggested a linear relationship but did not meet the assumption of normal distribution, the Spearman's rank-order correlation was applied. Neuropsychological measures suggesting a linear relationship and found to be normally distributed were evaluated using the Pearson's product moment correlation.

N170 ERP MEASURE

EEG amplitude values collected on the electrode groupings illustrated in Figure 1, for the time window 150-200 milliseconds post stimulus onset, were used to render waveforms for each condition between hemisphere within and between groups. Amplitude differences were statistically evaluated using Analysis of Variance (ANOVA) and followed by applicable post-hoc tests.

KEY FINDINGS: PRE-POST INTERVENTION

Post-intervention reading assessment scores and EEG data were evaluated to assess the effect of the intervention on the N170 ERP measure and to determine how such a neurophysiological index might be characterized behaviorally.

Pre-Post Comparisons: Behavioral Assessments Performance Change

Statistically Significant Increases in Scores Pre-/ Post-Intervention by Group									
	Wilcoxon Signed-Rank Tests								
Group	Phonics Inventory	Reading Inventory	WRMT-R/ WORD ID	CTOPP-2/ Phoneme Isolation	CTOPP-2/ Blending	CTOPP-2/ PA composite	TOWRE-2/ SWE	TOWRE-2/ PDE	TOWRE-2/ Total
TDA	N/A	$p = 0.046$	N/A	N/A	$p = 0.042$	$p = 0.046$	$p = 0.043$	$p = 0.027$	$p = 0.027$
TDD	N/A	N/A	$p = 0.041$*	N/A	N/A	N/A	N/A	N/A	N/A
SRD	$p = 0.042$	N/A	N/A	$p = 0.027$	N/A	$p = 0.034$	N/A	$p = 0.028$	N/A

Table 1. WRMT-R=Woodcock Reading Mastery Test-Revised-subtests, Word ID; CTOPP-2=Comprehensive Test of Phonological Processing-2nd Edition subtests Phoneme Isolation, Word Blending and composites scores for PA=Phonological Awareness; TOWRE-2=Test of Word Reading Efficiency-Second Edition- subtests SWE=Sight Word Efficiency, PDE=Phonemic Decoding Efficiency, TWRE=Total Word Reading Efficiency. N/A = Not statistically different. *Statistically significant decline in scores.

Post-intervention results compared to pre-intervention baseline outcomes (Table 1) reflect the enduring nature of differences between the SRD group and the TDA group on such measures as the *Phonics Inventory* and *Reading Inventory*.

Overall:

• For many of the performance measures, statistically significant differences were only observed between the SRD group and the TDA group (e.g., the WRMT- R Word ID and Word Attack subtests, the TOWRE-2 SWE and PDE subtests).

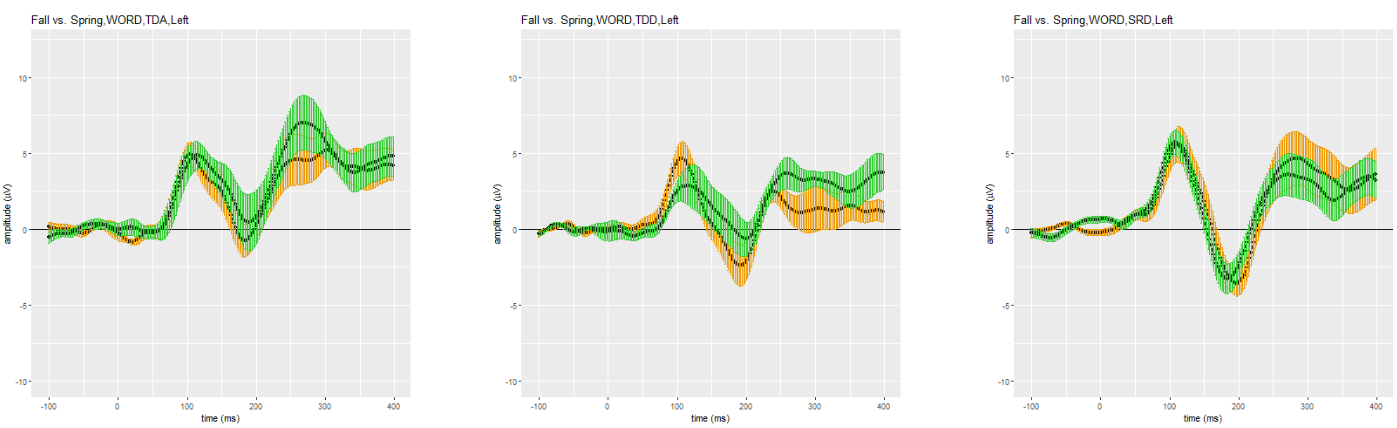
• The TDA group exhibited the highest performance on the TOWRE-2, and the TDD group performed less well than TDA but better than SRD. The SRD group is characterized by overall low performance on the TOWRE-2 (all 3 measures). Detailed assessment outcomes are available in the full Study Report.

• TDD and TDA groups performed comparably on the Orthographic Choice Task and the Homophone Choice Task, but the SRD group did not perform as strongly on these measures as their cohorts (Note: Tasks results not shown in Table 1).

• Decoding status did shift for some students in both the TDD and the SRD group (See Table 1).

• Many scores improved between time points, however some scores decreased (e.g., many of the students in the TDA and the TDD groups scored lower in the WMRT-R Word ID subtest at the second time point).

PRE-POST COMPARISONS: N170 ERP WAVEFORMS



TDA **TDD** **SRD**

Figure 3. Fall pre-intervention vs. Spring post-intervention for the WORD Condition in left hemisphere for each group.
Left Hemisphere – WORD Condition
Fall (Orange) & Spring (Green)

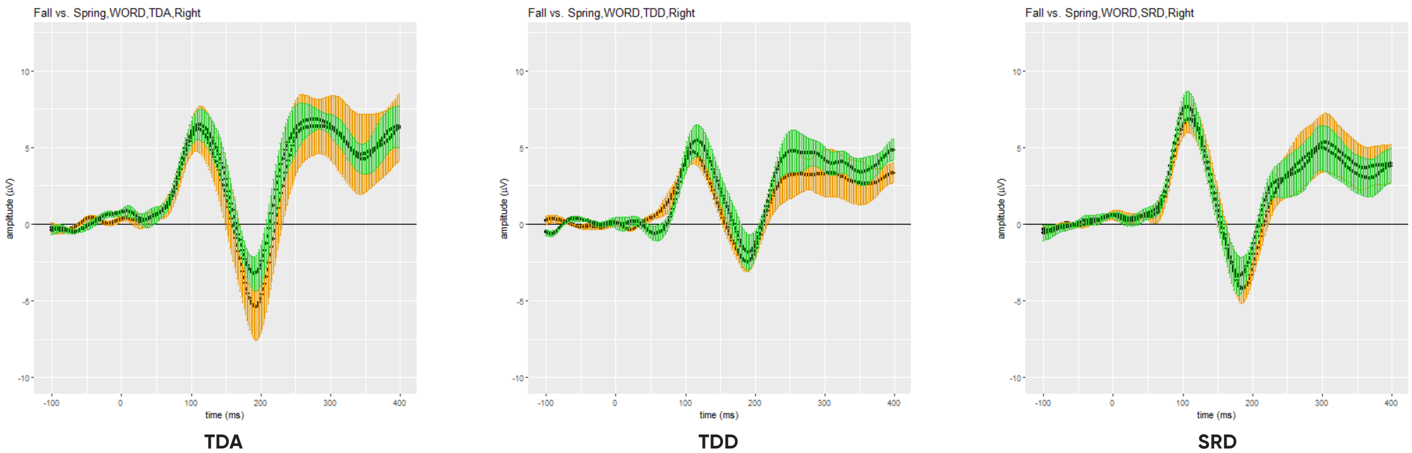


Figure 4. Fall pre-intervention vs. Spring post-intervention for the WORD Condition in right hemisphere for each group.
Right Hemisphere – WORD Condition
Fall (Orange) & Spring (Green)

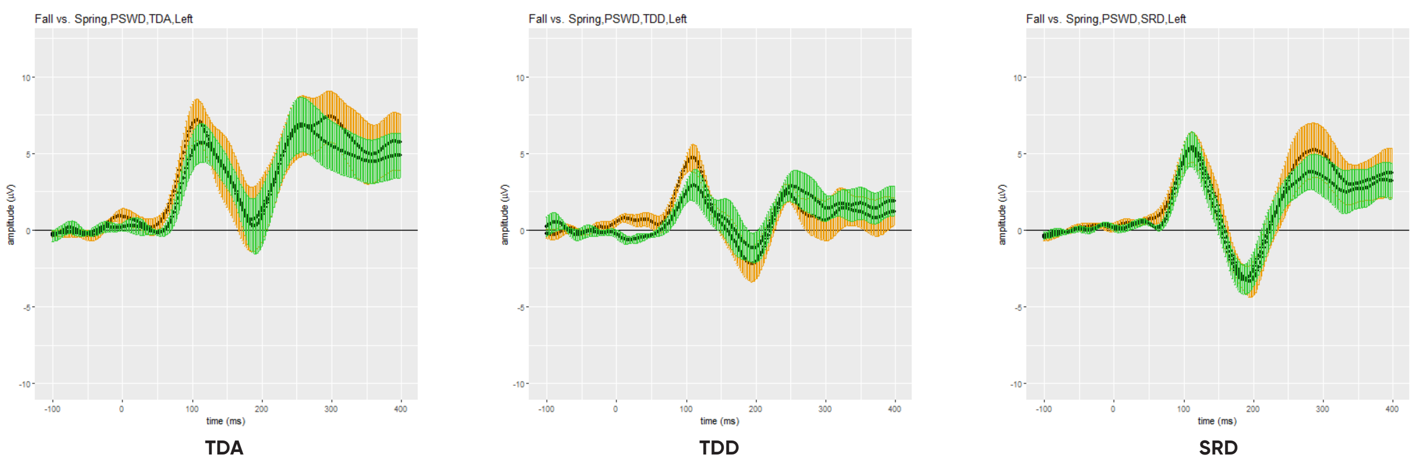


Figure 5. Fall pre-intervention vs. Spring post-intervention for the Pseudoword Condition in left hemisphere for each group.
Left Hemisphere – Pseudoword Condition
Fall (Orange) & Spring (Green)

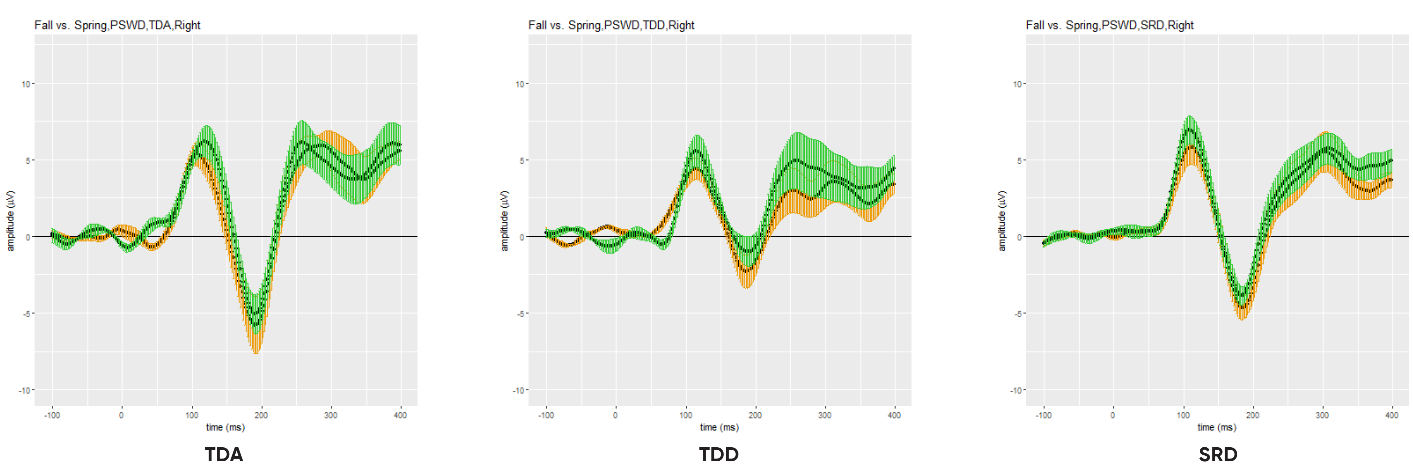


Figure 6. Fall pre-intervention vs. Spring post-intervention for the Pseudoword Condition in right hemisphere for each group.
Right Hemisphere – Pseudoword Condition
Fall (Orange) & Spring (Green)

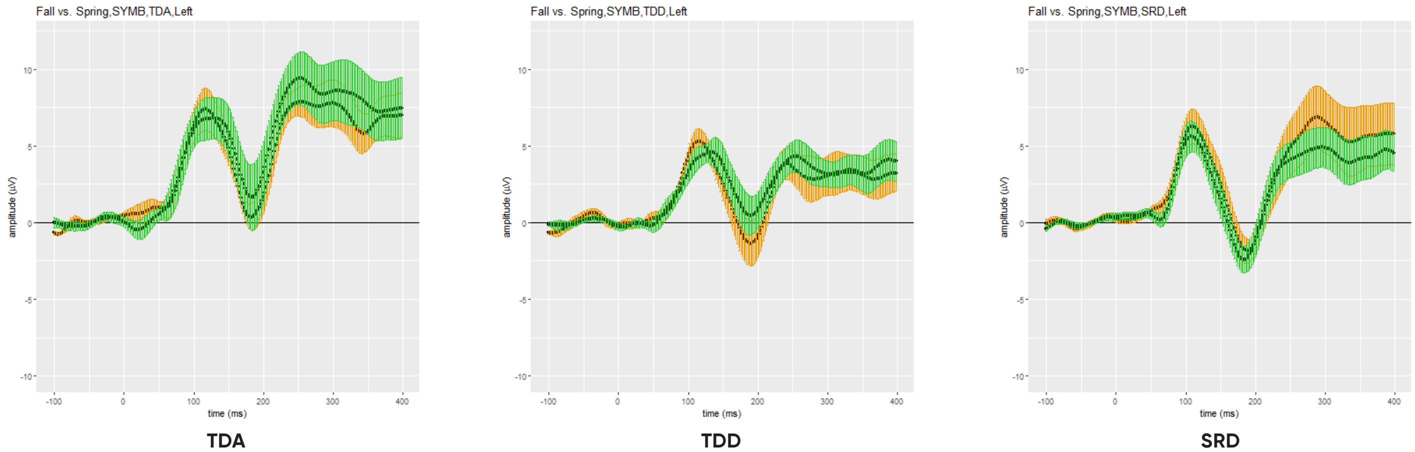


Figure 7. Fall pre-intervention vs. Spring post-intervention for the Symbol Condition in left hemisphere for each group.
Left Hemisphere – Symbol Condition
Fall (Orange) & Spring (Green)

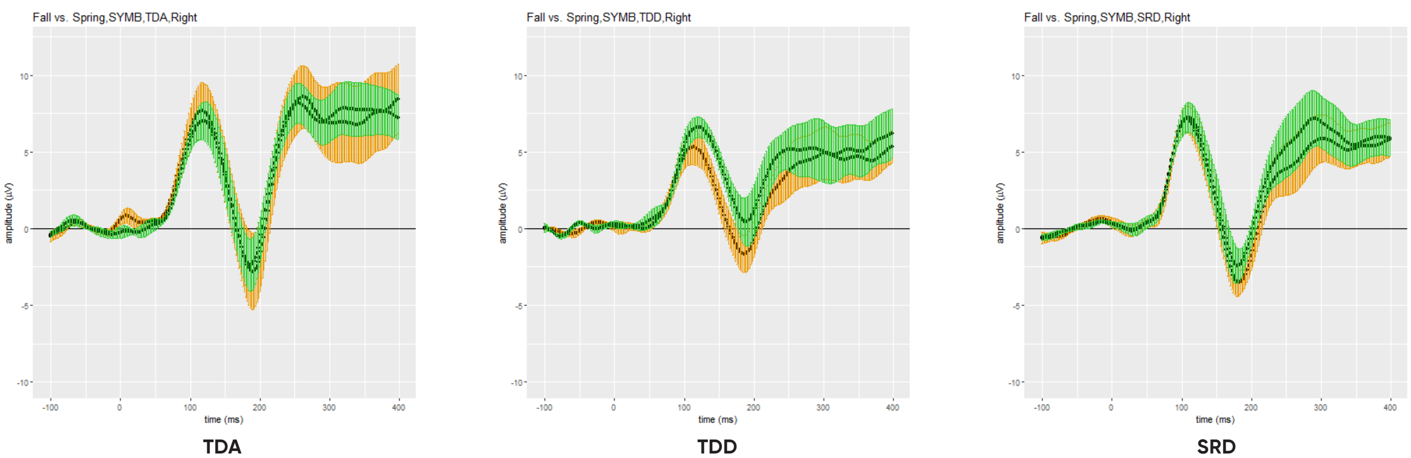


Figure 8. Fall pre-intervention vs. Spring post-intervention for the Symbol Condition in right hemisphere for each group.
Right Hemisphere – Symbol Condition
Fall (Orange) & Spring (Green)

Waveforms comparing the pre-intervention and post-intervention EEG recordings for each participant group for the three conditions by hemisphere are depicted in Figures 3-8. Visual inspection of the waveform plots reveals that the magnitude of the response is diminished for the TDA group in the left hemisphere compared to the right. For the TDD group difference between hemispheres appears negligible, however upon closer inspection there does appear to be a slight shift toward a less negative deflection in the left hemisphere. The SRD group waveforms for the pre-intervention and post-intervention time points appear unchanged for the hemisphere comparison. However, the observed left versus right hemisphere amplitude differences were not statistically significant for either the TDA or TDD groups, as was also true for the perceived amplitude differences in hemisphere comparisons between groups.

PRE-POST CORRELATIONS: N170 ERP AND BEHAVIORAL ASSESSMENTS

Moderate to strong positive correlations between neurophysiological and behavioral measures were seen only between left hemisphere N170 amplitude measures and specific assessment measures: *Reading Inventory*, *Phonics Inventory*, WRMT-2 Word Identification, WRMT-2 Word Attack, CTOPP-2 Word Blending, Orthographic Choice and Homophone Choice. These were also the assessments that tended to show the greatest differences between the SRD and TDA groups.

SUPPLEMENTAL ANALYSES

One of the repeated findings from intervention studies is that despite improvement in skills within groups, gaps between groups remain. When categorized into groups, individuals within a group rarely present homogenous profiles either with respect to reading skills or contributing factors. Participants in the SRD group reported a number of co-occurring disorders such as ADHD and speech/language disorders. As such, this group represents a sample of students with differing factors contributing to delayed reading mastery.

While reports from the parents of students in the TDD group indicated no difficulty learning to read, it would seem based on individual *Phonics Inventory* scores that not all had yet mastered the basics of fluent word decoding. This group might include students with an unidentified biologically-based reading disability or students who have not received adequate instruction in foundational reading skills. TDA participants all report typical reading progression, however members' reading assessment scores show differentiation in reading ability. Within group variance may be a source of insight into how best to support developing readers. The post-hoc supplemental analyses highlight how participant profiles did and did not shift over time.

CORRELATIONS BETWEEN READING ACHIEVEMENT AND THE N170 ERP

The correlation analyses for both the pre-intervention measures and the post-intervention measures suggested a strong positive relationship between left hemisphere amplitude measures across conditions and multiple behavioral measures. This observation prompted our conducting a series of regression analyses to explore the predictive value of different behavioral measures for left hemisphere word and pseudoword N170 amplitude measures. Simple linear regressions revealed that the *Reading Inventory*, *Phonics Inventory*, WRMT-R Word ID and Attack, CTOPP Word Blending, Homophone Choice Task, and Orthographic Choice Task all significantly predicted the N170 amplitude in the left hemisphere.

Linear regressions were followed by multiple regression analyses, which were applied to investigate how select combinations of some of these behavioral predictor variables relate to the N170 index. For the word condition, the analyses using *Reading Inventory* and *Phonics Inventory* as predictors of the N170 amplitude was not significant ($p = .057$). Scores on the Orthographic Choice Task and *Phonics Inventory* together did significantly predict amplitude over the left hemisphere in response to the word condition ($p = .014$).

Tests of multiple regressions were followed by a hierarchical regression performed on each of the conditions (Word, Pseudoword, Symbol) using *Phonics Inventory*, Orthographic Choice Task, and *Reading Inventory* assessments as independent variables.

With respect to the word condition, the most illuminating outcome was that scores on the *Phonics Inventory* and the Orthographic Choice Task together significantly predicted squared amplitudes over the left hemisphere in response to the word condition ($F(2, 16) = 6.932$, $p = .007$).

WITHIN GROUP VARIANCE: SRD PARTICIPANTS

Taken together, the correlation and regression analyses suggested that the Orthographic Choice Task scores had predictive utility in this situation. The outcomes prompted the question as to what reading skills beyond the decoding categorization might be contributing factors to the emergence of the oft noted less-negative left hemisphere N170 deflection. We investigated this proposition by reviewing within group variance. Here we discuss insights of note for the SRD participants.

For the SRD group, the CTOPP-2 Phonological Awareness composite score was the measure that saw the most group improvement; that is, more students improved on this measure than any other measures. The SRD group can be divided further into 2 groups: one group of students who did not show much improvement and another group who did (all three students in the latter group showed improved scores on the WRMT Word ID, TOWRE SWE and PDE (and subsequently TOWRE total). These three students (2 female, 1 male) have diverse profiles, came from different socioeconomic backgrounds and types of schools, with 2 out of 3 being diagnosed with ADHD (1m/1f). Interestingly, the two females speak more than one language and were introduced to this language at an early age (no later than age 5). These were the only two students from the SRD group who speak another language.

To speculate, it is possible that their bilingualism could contribute to comfort with phonemes being expressed in different forms, therefore setting them up for improvement. Interestingly, the male in this group improved on every single measure, but there was nothing characteristically diverse that marked his profile compared to the other 7 students in the SRD group, or the other 2 females who showed improvement. None of the students in the intervention program were categorized as Advanced Decoders, though 2 students were on the cusp (*Phonics Inventory* raw score of 22 following participation in the *System 44* program).

WAVEFORM OBSERVATIONS

For the TDD group, as previously stated, two study participants shifted from developing decoder status to advanced decoder status during the intervention period. The correlation analyses suggest that *Phonics Inventory* scores were statistically significantly associated with adaptive mean amplitude over the left hemisphere in response to the word condition, which led us to ask how the waveforms for these two students in the TDD group who shifted decoding status from developing to advanced decoder contrasted against grand averaged TDA and SRD waveforms. The waveform profile of TDD participant 1674 is shown below (Figure 9). The new decoding status of participants 1673 and 1674 did not result in individual waveform shifts to more closely mirror waveforms for the TDA group.

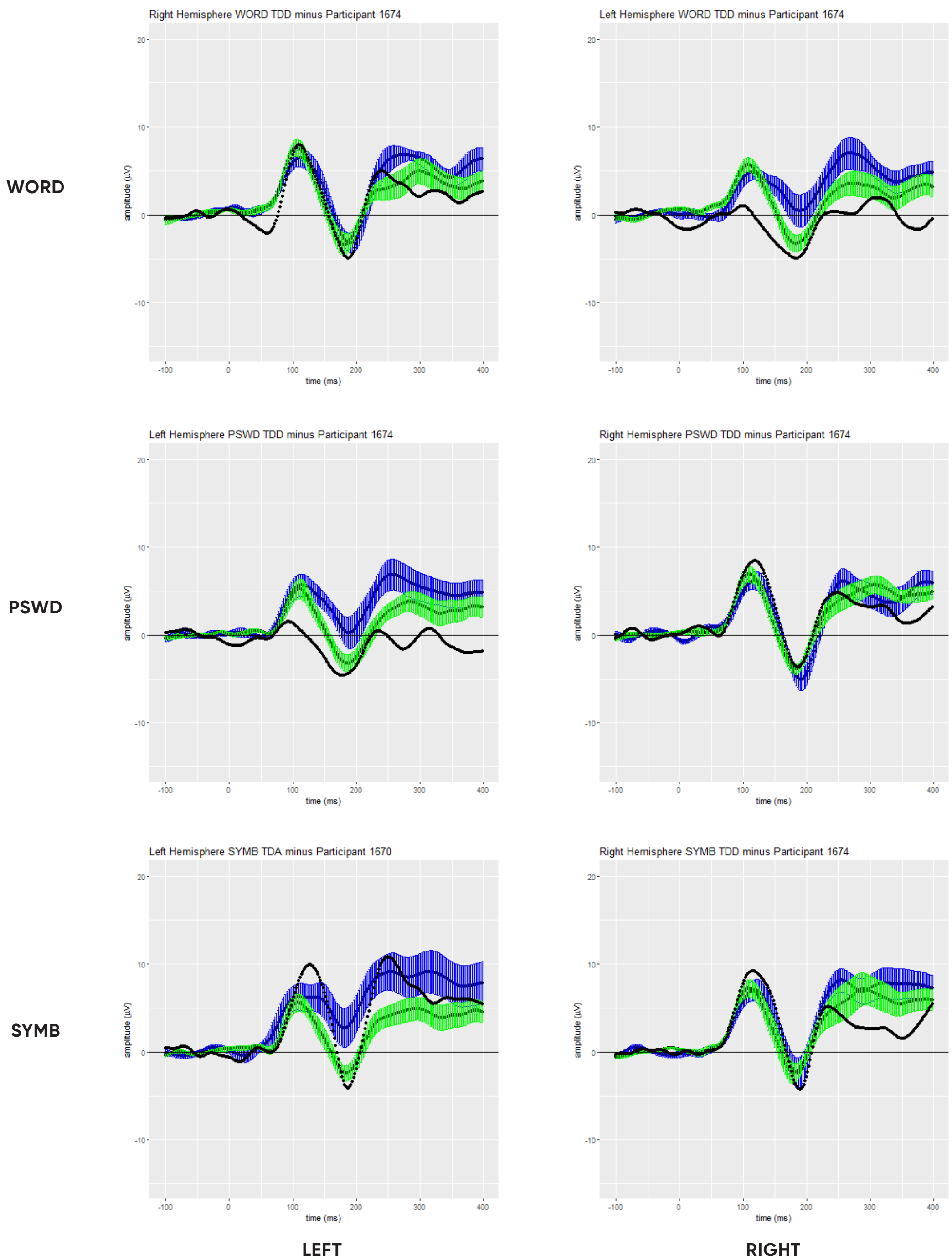


Figure 9. Waveform Comparison of TDD Participant 1674 with TDA and SRD Group
TDA Group = Blue & SRD Group = Green; Participant 1674 (TDD) = Black
Fall = Developing Decoder (18)/Lexile 748; Spring = Advanced Decoder (31)/Lexile 856

The N170 responses observed for the group of advanced decoders were attenuated relative to those observed in other cohorts of readers who attained automaticity (e.g., Maurer et al., 2006), even though expected lateralization effects were present. However, in reviewing the assessment data comparing fall and spring for each participant, it was determined that two of the TDA students (participants 1667 and 1670), despite being advanced decoders, had low scores relative to others in the group. We looked at their waveforms for all conditions contrasted against the grand averaged TDA and SRD waveforms. Comparison of the waveform profile of participant 1670 is shown in Figure 10 below. The student's waveform profile more closely follows the SRD group grand average.

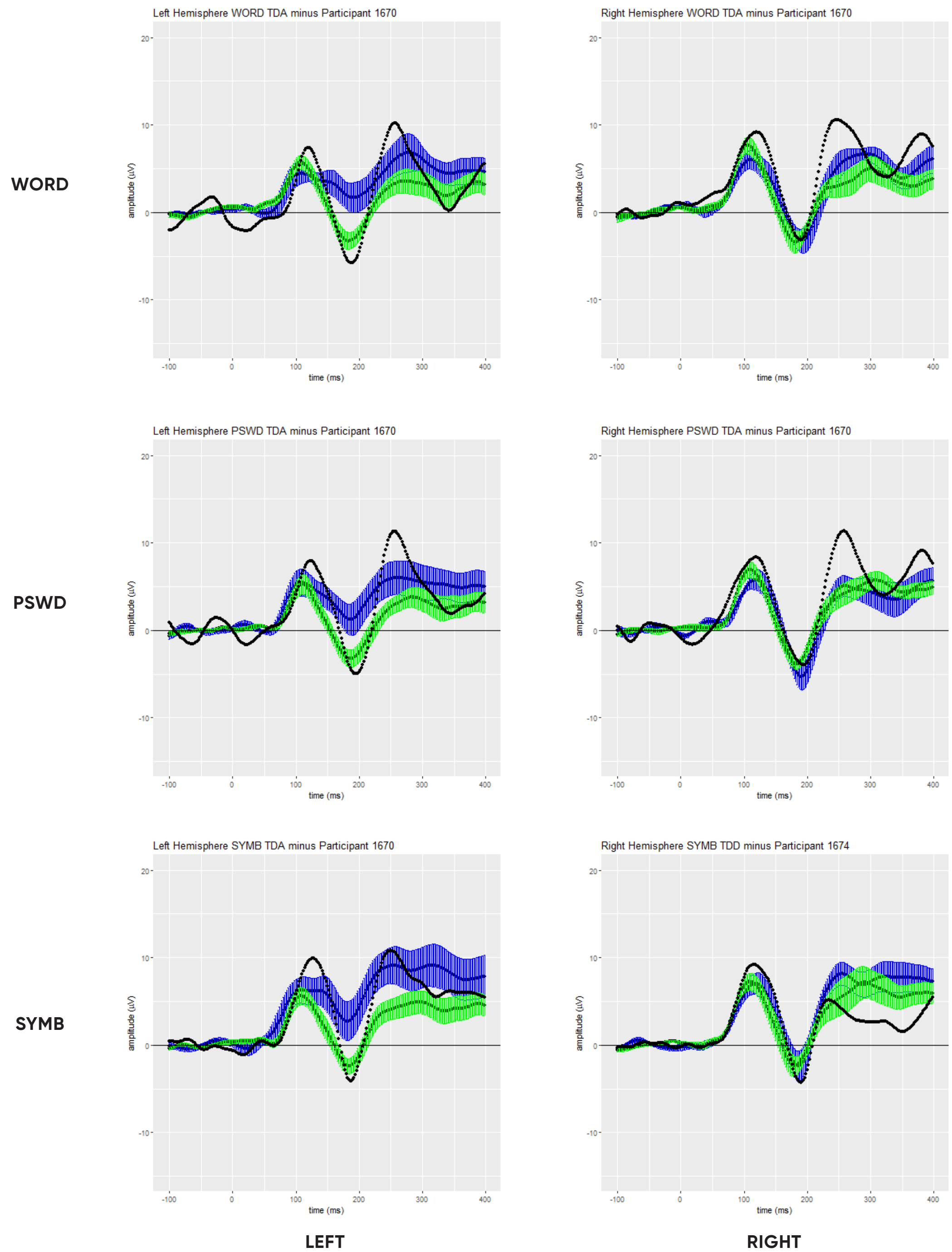


Figure 10. Waveform Comparison of TDA Participant 1670 with TDA and SRD Group
TDA Group = Blue & SRD Group = Green; Participant 1670 (TDA) = Black
Fall + Developing Decoder (27)/Lexile 797; Spring = Advance Decoder (23)/Lexile 852

Of the two TDD students who transitioned from developing to advanced decoders and the two TDA students in the advanced decoder group, only the TDA student with the highest *Phonics Inventory* score and the highest Orthographic Choice Task score also demonstrated an individual waveform that was similar to that shown by the TDA group as a whole. This is consistent with the multiple regression analyses, which confirmed that the Orthographic Choice Task and *Phonics Inventory* scores together significantly predicted amplitude over the left hemisphere in response to word processing. The interaction between and development of these skills appears to be crucial for successful literacy acquisition and the attainment of automaticity in reading.

SUMMARY OF SUPPLEMENTAL ANALYSES

The supplemental analyses serve to highlight the nature of the performance variances found in our sample groups and to suggest some of the mechanisms that contributed to this variance:

- Students who self-identified as typically developing readers were not all advanced decoders as might have been expected. In particular, the TDD sub-group, demonstrated a different waveform pattern than their typically developing peers who had advanced decoding skills. Some TDD participants transitioned from developing decoders to advanced decoders over the program period. At the group level, TDD waveforms suggested a shift toward a less negative N170 deflection, that is a response moving in the direction of the advanced decoder group.

- Closer inspection of the waveforms, in particular comparing individual waveforms against the grand averages for TDA and SRD groups, revealed that individual SRD students, even those on the cusp of becoming advanced decoders, look similar to their TDD counterparts on reading assessment measures, but did not approximate to the TDA-type waveforms.

- As for the TDD students who became advanced decoders, they too still mirrored the waveforms that were more typical of the SRD group.

CONCLUSIONS

The findings from the regression analyses revealed that the *Phonics Inventory* and the Orthographic Choice Task measures statistically significantly predict the N170 adaptive mean amplitude value in the left hemisphere for the word condition. To look more closely at how that might contribute to changes in the waveforms, scores from the *Phonics Inventory* and the Orthographic Choice Task were compared between students. The student whose waveforms looked most like the grand average of the TDA group had both the highest *Phonics Inventory* and Orthographic Choice scores. Therefore, while some students may be categorized as advanced decoders, it also seems to matter how those skills interact with orthographic processing skills.

Participant	Orthographic Choice Task	Phonics Inventory score	Waveform Comparison
1673	42	32	More SRD-like
1674	45	31	More SRD-like
1667	46	37	More TDA-like
1670	42	23	More SRD-like

Table 2. Orthographic Choice Task and *Phonics Inventory* scores for participants who either shifted from developing to advanced decoders (participants 1673 and 1674) or who we categorized as advanced decoders but with weaker assessment measures (participations 1667 and 1670).

Our study outcomes suggest that orthographic knowledge is a critical factor that interacts with phonemic skills to affect changes in N170 lateralization. The interaction between development of these skills is crucial for successful literacy acquisition and the attainment of automaticity in reading. In the present study, N170 changes seem to be related to building phonological and orthographic knowledge beyond a basic threshold, reflecting the interaction of phonological and orthographic skill development. This finding has significant implications of relevance to the theoretical debate around sight word reading and the importance of building decoding skills during literacy acquisition. In addition, it sheds light on the comparatively lengthy course of literacy acquisition and the requirement for formal instruction needed for striving readers that sets literacy development apart from language development in general.

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