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Orthographic and Phonological Processing in Beginning Readers

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ORTHOGRAPHIC AND PHONOLOGICAL PROCESSING IN BEGINNING READERS

By

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Abstract

Purpose – Both orthographic and phonological awareness are essential to reading, however, until recently the role of orthographic knowledge in phonological awareness has not been thoroughly investigated in beginning readers. The purpose of this study was to examine the relationship between orthographic and phonological knowledge in beginning readers and to establish a proof of concept for the use of eye tracking measures to examine these skills in young children.

Methods – 11 participants, aged 6-7 years completed norm-referenced assessments of language and reading ability and experimental measures of orthographic and phonological awareness while their eye movements were monitored.

Results – Participants processed orthographic information and accessed the constraints and regularities of the English orthography. This ability to possess and use orthographic knowledge influenced their phonological processing; participants spent longer and had more dwell times on incongruent items relative to congruent items.

Implications – Investigating orthographic interference in phonological processing and sensitivity to orthotactic probabilities may lead to a better understanding of these processes in typical development. This in turn lends itself to a better understanding of reading problems associated with dyslexia and improved evidence-based practices.

Introduction

As children learn to read, they rely heavily on two knowledge sources: letters and sounds. These sources are represented by the larger constructs of phonological awareness and orthographic knowledge. Phonological awareness is the ability to reflect on and manipulate the sounds of spoken language (e.g., /m/ is the first sound in *mop;* Cain, 2010). Children decide how to represent these phonemes because orthographic processing entails the ability to acquire, store, and use letters and letter patterns (Apel, 2011). Orthographic knowledge is the knowledge of how letters represent sounds in spoken language (Apel, Wolter & Masterson, 2006). Together, phonological awareness and orthographic knowledge are the two most important early predictors of reading outcomes (Bus and Van IJzendoorn, 1999; Treiman, 2006; Mol & Bus, 2011).

Understanding that letters represent the phonemes (sounds) of spoken language is called the alphabetic principle, and this principle along with the ability to identify and manipulate phonemes, or phonemic awareness, are the key building blocks of reading an alphabetic orthography. Phonemic awareness was identified by the National Reading Panel (2000) as one of the 'big five ideas' of reading.

Phonological Knowledge

Phonological awareness is a broad umbrella term that includes all the specific levels of speech-sound based awareness. Overall, phonological awareness "manifests as the ability to attend to and make judgments about the general sound structure of language" (Schuele & Boudreau, 2008, pg. 6). Typically, syllable awareness and rhyme awareness develop first, leading this awareness to be considered phonological sensitivity (Lonigan, Burgess, Anthony & Barker, 1998 as cited in Schuele & Boudreau, 2008). As the stages of phonological awareness are mastered, complexity increases, allowing phonemic awareness, or the ability to manipulate individual phonemes, to

develop. Onset-rime segmentation is the beginning of the development of phonemic awareness; a phonological rime is the string of sounds that follow the first sound, which is considered the onset, so onset-rime segmentation is the ability to understand and segment the first sound in a word and the following sounds (Schuele & Boudreau, 2008). As one becomes more adept at manipulating phonemes, he or she begins to develop the ability to segment initial and final sounds, blend sounds into words, segment words into sound, and delete phonemes. Through these increasingly complex skills, phonemic awareness teaches children to attend to sounds, priming the connection of sound to print or the alphabetic principle. Additionally, phonemic awareness helps children notice the regular ways that letters represent sounds in word. These abilities established by phonemic awareness enable decoding and spelling.

Orthographic Knowledge

Being able to decode and spell is immensely important as these abilities foster reading development and progression. There are various ways to read words; the self-teaching hypothesis explains how children move through the stages of learning to recognize words by proposing that word-learning occurs at an item-based level (Share & Stanovich, 1995; Share 1999). The self-teaching hypothesis posits that phonological decoding – or the "sounding out" of a word—functions as a self-teaching mechanism. Each time a child decodes an unfamiliar word he or she initiates a mental representation of the pronunciation and spelling of the word; after successfully decoding a word several times a robust "mental graphemic representation" is formed. Thus, phonological decoding acts as a "built-in teacher enabling a child to independently develop the word-specific orthographic representations essential to skilled reading and spelling" (Share, 1999, pg. 96). These mental graphemic representations along with knowledge of the spelling rules and patterns of a language comprise orthographic knowledge.

The orthographic knowledge of skilled readers influences their speech perception and phonological awareness. Frith (1998) famously compared orthographic knowledge to a virus, which "infects all speech processing, as now whole word sounds are automatically broken up into sound constituents. Language is never the same" (p. 1011). This infection of orthographic knowledge was first demonstrated by Seidenberg and Tanehaus (1979) who found throughout three experiments in their study that even when young adults did not see the graphemes of a word and only received an aural presentation of the word, they still activated their orthographic knowledge on a rhyme detection task. Participants were faster to detect rhymes when primed by an orthographically similar word presented either aurally or visually. This finding supports the idea that accessing orthography occurs without conscious effort in skilled adult readers. Therefore, orthography influences phonological processing in skilled adult readers (Castles, Holmes, Neath & Kinoshita, 2003; Seidenberg & Tanehaus, 1979).

Another by Ziegler and Ferrand (1998) demonstrated how orthography influences phonological processing of skilled adults using French university students. Individuals took longer to make lexical decisions (i.e., to discern if a string of letters was a real word) and made more errors in an auditory word perception task when they heard words with phonological rimes that could be represented by multiple graphemes (letters) in comparison to words with phonological rimes that could by represented by only one combination of graphemes. These results reveal that orthographic information is connected to and coactivated with phonological information in skilled adult readers. This influence can take shape by slowing down and even causing errors in phonological processing when more than one orthographic possibility exists for a word.

Only a few studies have examined how orthography influences the phonological

processing of children. Castles, Wilson, and Coltheart (2010) demonstrated that the emerging orthographic knowledge of preschoolers, which consisted of their knowledge of some letter-sound correspondences, influenced their performance on phonemic awareness tasks. This was a training study as participants were trained in one of two sets of eight letters/sounds; the set that they learned in their group constituted their trained items, and the other set of letters/sounds constituted their untrained items. After taking a pretest that assessed phonemic awareness and letter-sound knowledge, participants completed training in a randomly assigned group that focused on either phoneme awareness, letter awareness, or a control group that used pictures. Then, the participants completed an intermediate test measuring phonemic awareness, which was followed by all participants learning the letter-sound correspondence for whichever set of trained items they had. The posttest taken after both sessions of training revealed that the children performed better on phonological awareness tasks using the trained letter-sound correspondences compared to the untrained ones. They hypothesized that basic letter knowledge was able to influence the participant's performance on the phonemic awareness task because "any available orthographic knowledge provides an extra memorial aid" (Castles et al., 2010, pg. 208).

Whereas Castles and colleagues (2010) focused on explicitly taught letter-sound associations, a study by Landerl, Frith, and Wimmer (1996) found that typically-developing (TD) 8- and 12-year-old children experienced more orthographic intrusion on phonological awareness tasks in comparison to 12-year-old children with dyslexia. Participants completed three phonological awareness tasks (i.e. phoneme counting, deleting the last phoneme, deleting the first phoneme) that each had two conditions. In the control condition words with phonologically transparent spellings were presented. In the second condition, or the silent letter condition, words that rhymed with the control items were presented, but they included a letter that is phonologically obsolete (e.g. lamb, what). This experiment design measured orthographic

intrusion, or when orthographic information influences and interferes with one's performance on phonological awareness tasks in an inhibitory manner. The silent letter condition would be difficult for participants if orthographic information influenced phonological processing when counting or deleting phonemes. The results showed that TD 8- and 12-year-old-children experienced orthographic intrusion, but the children with dyslexia did not show intrusions to the same extent. The findings of Landerl and colleagues (1996) have not been built on as few studies have examined the effect of orthographic knowledge on phonological processing in beginning readers, and this investigation would be useful to contrast with children with dyslexia who show core deficits in phonological processing.

Overall, these studies have investigated how orthography influences children's and adult's phonological processing. However, this current study offers new insight into the investigation by assessing beginning readers using eye tracking. The studies discussed above that examined orthographic knowledge and phonological processing used tasks that would have ceiling effects for older children. As children become skilled readers, a long set would be needed to capture ability through phonological processing tasks. Eye tracking, however, allows more information other than accuracy to be obtained, and this information reveals the cognitive processing experienced by children while completing tasks. Eye tracking enables the ability of a wide range of skills to be captured in children concerning reading. Therefore, our study will contribute to expanding the knowledge of how orthographic knowledge influences phonological processing in beginning readers by employing eye tracking measures.

Using Eye Tracking to Measure Processing

Most studies of early literacy development have relied on behavioral measures of accuracy. One limitation of these measures is that they do not indicate the cognitive processes that a child

experiences prior to making a response. An advantage of eye tracking methods is that it enables researchers to examine the cognitive processes underlying a child's decision on a task by providing a window into the processing before a response is made. Another issue with using tasks based on accuracy or fluency alone is that they will not be sensitive to individual differences at every age or grade (cf. Catts, Petscher, Schatschneider, Sittner Bridges & Mendoza, 2009).

In order to examine the cognitive processes that lead to a child selecting a response, the fixation patterns and the fixation duration of a child are examined, and these reveal where and when children encounter difficulties (Raney, Campbell & Bovee, 2014). The process of looking at a visual world paradigm entails fixations, when the eyes are at rest and taking in information, and saccades, which is the movement of the eye from one location to the next, and in the case of this experiment, from one set of letter strings or one picture to the next. The information that one gleans from fixations becomes a part of one's cognitive experience. Eye tracking permits researchers to study the fixations and saccades that occur while an individual is engaged in visual perception. Preliminary work has shown that even young children can do eye tracking tasks and that it relates to their ability (Ashby, Dix, Bontrager, Dey & Archer, 2013).

The Present Study

The purpose of this study is to examine the relationship between orthographic knowledge and phonological processing in typically developing 6-7-year-old children. First, we examine typically developing (TD) six-and-seven-year-old children's sensitivity to orthotactic probabilities at a more fine-grained level than in past studies. Next we ask whether TD 6-7-year-old children experience orthographic interference during a phonological awareness task. In order to examine these two research questions, we use experimental eye tracking tasks. Finally, we

will examine the correlation between eye movement measures of phonological and orthographic processing and norm-referenced measures of early literacy skills. We predict that performance on the phonological and orthographic processing tasks will be correlated with literary scores of six-and-seven-year-olds.

Method

This study involved TD 6-and-7-year-old children. All study procedures were approved by the University of South Carolina Institutional Review Board prior to data collection. The participants completed two experimental eye tracking tasks measuring orthographic processing and phonological processing as well as a battery of norm-referenced assessments of language and reading. The complete battery of assessments required approximately one hour and thirty minutes and was completed in one session. All of the tasks were administered in a fixed order, and frequent breaks, snacks, and incentives were offered to facilitate participant engagement and motivation.

Participants

We recruited 13 subjects, and two participants were excluded from this study because their norm-referenced results showed that their reading and language skills were below normal limits. The current sample includes 11 participants aged 6:4-7:7 (mean =7:0; *SD* =0.5; 7 males, 4 females). Nine participants identified as white, one participant identified as Latino, and one participant identified as African American. Testing began at the end of the first half of the academic year and continued throughout the second half of the academic year. Participants were drawn from various avenues including an event for families of students entering kindergarten and flyers posted on social media pages. Parent reports indicated no concerns about speech, language, and cognitive development. We are continuing to recruit subjects to achieve a planned sample size of 32.

Eye Movement Tasks

Participants performed a phonological processing task and an orthographic processing task

designed by Adlof, Hogan, & Ashby (2017). The phonologic and orthographic tasks were designed to be relatively easy for elementary school students; therefore, we predicted that the tasks would be challenging for six-and-seven-year-olds, but not impossible. Participants' eye movements were monitored during the tasks using a desktop mount Eyelink 1000 Plus eye tracker in the remote mode. The remote mode was ideal for the age group of this study as it allows participants to make small movements and not have to sit entirely still for the duration of the tasks.

Eyelink's Experiment Builder software controlled the presentation of auditory and visual stimuli and recorded the eye movement data. Each participant performed a 9-point calibration procedure before each task began, and drift correction was utilized before each trial within the task. Each task began with two practice items in a video format in order to familiarize participants with the procedure, and participants received feedback about their accuracy on these items only.

Phonological Processing Task

This eye-tracking task assessed participants' ability to identify and compare the final phonemes in spoken words. Participants saw four pictures and heard four recorded words naming them. Then participants were instructed to "click on the picture that ends with the same last sound as [stimulus]". The correct answer in each trial was the picture that ended with the same phoneme as the stimulus word. The foil words and pictures included one that began with the same sound as the stimulus word, one that began with the last sound of the stimulus word, and one that ended with a sound that differed from the stimulus word's last sound by one feature (voice, manner, place). In each trial of the task, the foils were comparable according to standard metrics from child databases, such as frequency, phonotactic probability, and neighborhood density (e.g.,

Moe, Hopkins & Rush, 1982; Storkel & Hoover, 2010).

Figure 1. Example item from the phonological processing task. The left panel shows the beginning of the trial. As participants view the screen, the four pictures are named, left to right, top to bottom: "gift, desk, hand, log. Click on the picture that has the same last sound as ..." As the stimulus word is named, "...dog," its picture appears above the four answer choices (right image). For this orthographically consistent item, the correct answer (log) shares the same final phoneme /g/ and grapheme <g> with the stimulus.

Congruency refers to the relationship between the phonemes and graphemes of words. Congruent words have phonemes represented by the same graphemes, whereas incongruent words have the same phonemes that are represented by different graphemes. Consistency indicates how phonemes are represented by graphemes in English orthography. Consistent items are ones in which phonemes have only one matching grapheme; for example, the phoneme /g/ can only be represented with the grapheme <g>. Inconsistent items, however, have phonemes that can be represented with more than one graphemic option; the phoneme /ks/ can be represented with either <cks> or <x>.

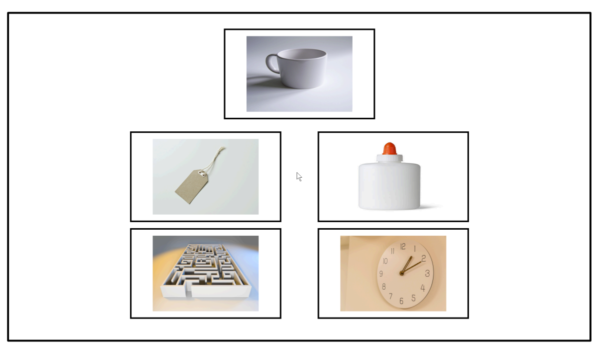

Figure 2. Example trial from the congruent consistent phonology set in the phonological task.

One third of the items involved congruent-consistent orthography in which the stimulus word and the target word used the same grapheme to represent the final phoneme, and those phonemes do not appear in word final position in the other conditions (e.g., mug and tag in Figure 2). The second third of the items

were labeled incongruent orthography in which the stimulus word and the target word used different graphemes to represent the same final phoneme (e.g. blocks and fox in Figure 3). The final third of the items were labeled congruent-inconsistent orthography in which the stimulus word and target word used the same graphemes to represent the final phoneme, but other graphemes were used to spell the same phonemes within the set of incongruent orthography items (e.g. bricks and clocks in Figure 4).

Figure 3. *Example trial from the incongruent phonology set in the phonological task. These words have the same target phonemes as the congruent-inconsistent.*

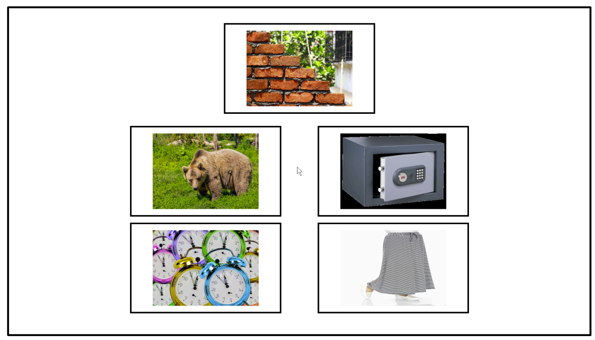

Figure 4. *Example trial from the congruent-inconsistent set in the phonological task. These words have the same target phonemes as the incongruent items.*

This task is designed to assess if participants' orthographic knowledge interferes with their phonological processing because participants are told to match the phonemes of the pictures, and while the correct option always has the same phoneme, the graphemes representing the phonemes may be different. The participants will not visually see the graphemes of the word the picture is depicting, but they will aurally hear the word; if this aural presentation activates the participants' orthographic knowledge, then it could influence how they phonologically process the phonemes of the words. The incongruent items are predicted to be more difficult while the congruent consistent items are predicted to be the easiest for participants. If participants had a more difficult time (as determined by lower accuracy, longer response times, and longer dwell times for each response option) processing the items with inconsistent graphemes compared to

the items with consistent graphemes, then this would be evidence of orthographic interference during phonological processing.

Orthographic Processing Task

This eye-tracking task measured how quickly participants processed orthographic information and accessed their awareness of the constraints and regularities of English orthography. For each trial, participants saw four strings of letters, and then they were instructed to look at the string that most closely resembled a real English word (see Figure 5). The correct answer in each trial was a pronounceable letter string that had a high orthotactic probability, meaning it contained a sequence of letters that commonly occur together in English (*clar*). The foils included a string of unpronounceable consonants (*bcsr*), a string of letters that began with an illegal diagraph (*hvej*), and a pronounceable string with low orthotactic probability (*glip*). Orthotactic probability for the targets and foils was determined from Hogan & Wolter's orthotactic probability calculator (Wolter, Hogan, Farquharson, Covington & Wang, 2014). The location of the correct trial and foil types were counterbalanced using a Latin Square. We predicted that participants would have more and longer fixations on legal strings than illegal strings, and we tested whether they differentiated between low and high probability legal strings (*glip* > *clar* > *hvej* > *bcsr)*.

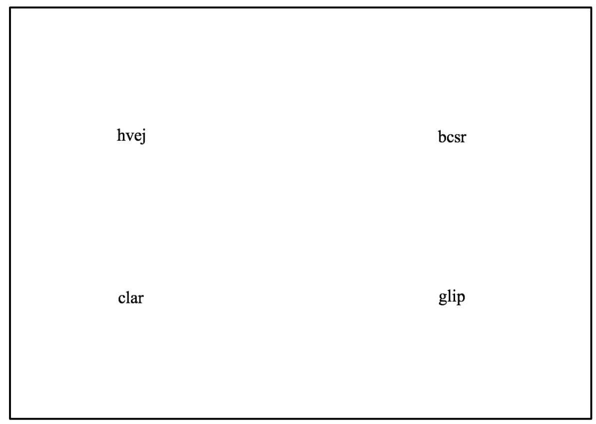

Figure 5. *Example trial from the orthographical processing task. Participants were instructed to click on the option that looks most like a real English word.*

Descriptive Measures

In addition to the eye tracking measures, participants also completed the Identification Core for 6-and-7-year-olds from the Test of Language and Literacy Skills (TILLS) (Nelson, Plante, Helm-Estabrooks & Hotz, 2016). This core consists of the vocabulary awareness subtest, the phonemic awareness subtest, and nonword repetition subtest. These psychometric assessments were given to verify that participants' word reading and language abilities were within normal limits and to validate eye-movement measures with norm-referenced analogs. Participants additionally received the Letter-Word Identification subtest of the Woodcock Johnson-III. Participants had to score within normal limits on all tests to be considered for the study.

Vocabulary Awareness

The vocabulary awareness subtest assesses children's lexical knowledge, awareness of semantic relationships, and cognitive-linguistic flexibility. Participants are presented with three words, and are then asked to identify a semantically related pair and provide an explanation for their choice. Participants are then asked to identify a second and different semantically related pair from the three words and explain their choice. For example, the first practice item consists of the words dog, cat, and bone. The first semantically related pair is dog and cat with the potential explanations that they are both animals or they are both pets. The second semantically related pair is dog and bone, and potential explanations for this choice are that dogs like, eat, chew, or bury bones. Participants are not required to use the exact reasons provided in the examiner record form to explain their choice; instead, participants receive points by choosing the right pair of words and having a correct semantic relationship as the reason for the selection. The test manual reports that test-retest reliability is = .95, coefficient alpha = .99, and interrater reliability = .866.

Phonemic Awareness

The phonemic awareness subtest assesses children's ability to identify and manipulate phonemes. Participants hear a made-up word and are then asked to say the word without the first sound. The test manual reports that test-retest reliability is = .88, coefficient alpha = .99, and interrater reliability = .98. In addition to being part of the identification core, this subtest allowed us to make a comparison to the experimental eye tracking phonological processing task.

Nonword Repetition

The nonword repetition subtest assesses children's speech perception, working memory, and speech production. Participants hear a recording of a made-up word and are asked to repeat the made-up word aloud. The test manual reports that test-retest reliability is = .81, coefficient alpha = .98, and interrater reliability = .91.

Procedures

The experimental eye tracking tasks, the TILLS subtests, and the Woodcock Johnson Letter-ID subtest were administered during a session lasting approximately one hour and thirty minutes. Five examiners participated in the administration of the experimental tasks and standardized assessments. One of the examiners was a certified speech-language pathologist in a Ph.D. program, two of the examiners were second-year students in the Masters of Speech Language Pathology at USC, one of the examiners was a certified SLP working as a postdoctoral student in the SCROLL Lab, and the other examiner was an undergraduate student. All examiners participated in a two-hour training session prior to experimental testing, which included training on test administration and experimental task presentation. The examiners had to study the manual for the standardized test and the protocols for the experimental tasks, and then they had

to observe someone giving the standardized tests and experimental tasks. For the last step of training, the examiners had to serve as the assessor who gave the test to the trainer.

Results

Descriptive information about participant sample is provided in Table 1, which displays scores on norm-referenced assessments on reading and language. All participants included in analyses scored within normal limits on these assessments.

Table 1

Standard Scores for Identification Core for 6-and-7-year-olds of the TILLS and the Letter-Word Identification subtest of the Woodcock-Johnson IV

Variable	**N**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age	11	7:0	0.5	6:4	7:7
TILLS Vocabulary Awareness Subtest	11	11.36	1.75	9	15
TILLS Phonemic Awareness Subtest	11	10.82	1.83	8	13
TILLS Nonword Repetition Subtest	11	11	1.95	7	14
Woodcock Johnson-IV Letter-Word Identification	9	116.78	11.73	100	130
WRMT-III Word Identification	2	111.5	9.19	105	118
WRMT-III Word Attack	2	104.5	4.95	101	108

**The first two participants received the WRMT-III Word Identification and Word Attack subtests instead of the Woodcock-Johnson-IV Letter-Word Identification subtest.*

If students are aware of orthographic constraints, which allows them to differentiate between legal and illegal letter strings, and are sensitive to orthographic regularities including co-occurring letter patterns in varying word positions (orthotactic probabilities), then the students ought to show a preference for high orthotactic probability items, followed by low orthotactic

probability items, and they ought to reject illegal and unpronounceable strings. The first row in Table 2 displays the mean number of trials for which each item type was selected. Results show that the participants did select high probability items most often (10.67 out of 18), followed by low probability items (4.42). The eye tracking data support the accuracy data and also enables factors that concern processing such as number of fixations and length of fixations to be considered in the analysis of the response choices. The second row in Table 2 shows the average number of fixations for each item within each trial, indicating that children made more fixations on legal (high, 2.38, and low orthographic probability, 2.07) strings than illegal (1.58) and unpronounceable strings (1.39). The third row in Table 2 shows the mean dwell time (the sum of all fixation durations) for each item within each trial, displaying that children spent more than twice as much time looking at legal strings than illegal strings. This pattern of raw data also suggests that the children made more fixations and spent more time looking at high orthotactic probability items than low orthotactic probability items. Taken together, the data seem to suggest that TD 6-7-year-old children are sensitive to both orthographic constraints and orthographic regularities. After we complete our data collection, we will run significance tests to determine whether these results are statistically significant.

Table 2

Mean Response Type, Response Time, and Dwell Times for Typically Developing Participants in Orthographic Processing Task

Variable	High Orthotactic Probability	Low Orthotactic Probability	Illegal String	Unpronounceable String
Mean number of trials selected (max=18)	10.67	4.42	0.75	0.67
(SD)	(4.85)	(2.31)	(2.01)	(1.50)
Mean number of fixations per trial	2.38	2.07	1.58	1.39
(SD)	(0.68)	(0.84)	(0.32)	(0.37)
Mean dwell time (ms) per trial	1.91	1.32	0.69	0.60
(SD)	(0.76)	(0.54)	(0.35)	(0.40)

If orthographic knowledge influences phonological processing, we should see that the congruent-consistent condition requires the least amount of cognitive effort (e.g., mug, tag), the congruent-inconsistent condition requires moderate cognitive effort (e.g., clocks, bricks), and the incongruent condition requires the most cognitive effort (e.g., blocks, fox). The first row in Table 3 displays descriptive statistics for the accuracy of selecting the correct response. The remaining rows display the average dwell times for each response option in each correct trial. The dwell time equals the sum of all fixation durations on an interest area, which in this case was a response option. Accuracy was highest, and response times were shortest for the congruent-consistent condition, followed by the congruent-inconsistent condition, and then by the incongruent condition. The exception to this is the foil 3 response option in the congruent-consistent, which had a higher accuracy than the congruent-inconsistent, but a longer dwell time. Across all response options within each condition, dwell times were longest for the target. However, across conditions, dwell times were shorter for congruent-consistent and congruent-inconsistent conditions compared to the incongruent condition. Taken together, these descriptive

data suggest that orthographic knowledge influences phonological processing in TD 6-7-year old children. After we complete our data collection, we will run significance tests to determine whether these results are statistically significant.

Table 3

Accuracy, Response Time, and Dwell Times for Typically Developing Participants in Phonological Processing Task

Variable	**Congruent-Consistent**	**Congruent-Inconsistent**	**Incongruent**
Mean percent correct (SD)	73%	70%	64%
Mean dwell times for each response option (second) (SD)			
Target	5.30 (0.88)	5.50 (0.62)	5.89 (0.76)
Foil 1 (initial phoneme of foil matches final phoneme of stimulus word)	3.55 (0.64)	3.72 (0.47)	4.43 (1.03)
Foil 2 (initial phoneme of foil matches initial phoneme of stimulus word)	3.42 (0.46)	3.50 (0.68)	3.94 (0.78)
Foil 3 (final phoneme of foil differs from stimulus final phoneme by one phonetic feature)	3.75 (0.78)	2.96 (0.60)	3.59 (0.82)

The eye movement data from the orthographic processing and phonological processing tasks will be filtered and processed using Eyelink's Data Viewer software. This data will be analyzed in SPSS to see if (1) a significant difference is found in accuracy, fixation location, and fixation duration between incongruent, congruent-consistent, and congruent-inconsistent items in

the phonological processing task; (2) a significant difference in accuracy, fixation durations, fixation locations for high orthotactic probability strings is found in the orthographic processing task; and (3) significant correlations exists between eye-tracking tasks and standard scores in the normative measures of early literacy.

Discussion

Data collection is still in progress, and statistical significance tests will be run when data collection is complete for the full sample. Our findings demonstrate that typically developing 6-and-7-year-old children show sensitivity to orthotactic probabilities because participants had more and longer fixations on legal strings than illegal strings and also selected legal strings more frequently than illegal strings. Participants were also quickly able to determine that the illegal strings and unpronounceable strings were not orthotactically probable based on the low dwell time, the low selection, and the low number of fixations these illegal letter strings received in comparison to the legal strings. Additionally, there was a distinction between the length and number of fixations on the letter strings that had a higher orthotactic probability compared to the letter strings with a lower orthotactic probability. This shows that participants are aware of and sensitive to the constraints and regularities of English orthography.

Regarding the phonological processing task, participants were less accurate on incongruent items and spent longer on average looking at them relative to congruent items. This demonstrates that participants had a more difficult time processing the items with inconsistent graphemes compared to the items with consistent graphemes. The differences between congruent-consistent and congruent-inconsistent items are smaller, but this suggests that congruent-consistent items may require less cognitive effort to process due to the consistent mapping of the graphemes that represent the target phonemes. The results of this study demonstrate that TD 6-7 year-olds have sufficient orthographic knowledge based upon their speed of processing orthographic information and accessing the constraints and regularities of English orthography; their orthographic knowledge is therefore sufficient to influence their phonological knowledge. Overall, our results reveal that orthographic interference occurs during phonological processing in beginning readers.

The results from the eye-tracking tasks offer a glimpse into the cognitive processing that occurred while the participants completed the processing tasks. This glimpse allows finer distinctions to be made that cannot be determined through standard measures. Investigating orthographic interference in phonological processing and sensitivity to orthotactic probabilities may lead to a better understanding of these processes in typical development. This in turn lends itself to a better understanding of reading problems associated with dyslexia and improved evidence-based practices.

A future study will examine these effects in older students with reading and language impairment as compared to these younger, typically developing readers. This study offers evidence that beginning readers not only possess orthographic knowledge, but that this knowledge influences their processing of sounds; this will assist in the development of a better understanding of reading problems in older students.

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