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Measuring orthographic influences on phonological processing in beginning readers: An eyetracking study

By

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Bachelor of Arts
University of South Carolina, 2019

Submitted in Partial Fulfillment of the Requirements

For the Degree of Master of Science in

Speech-Language Pathology

Arnold School of Public Health

University of South Carolina

2022

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Acknowledgements

This work was supported in part by the South Carolina Honors College Exploration Scholars Research Program, by a USC Magellan Scholar Award to Emily Fisher, and by an ASH Foundation Clinical Research Grant (PI: Adlof). We are grateful for the participants in the study; collaborators Jane Ashby and Pete Shlanta, who assisted with eyetracking methods; and SCROLL Lab members who helped with data collection, processing, and analysis including Anna Ehrhorn, Karsyn Blanton, Alex Marion, Sarah Gerth, and Grace Carroll.

Abstract

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

Method – 22 participants, aged 6-7 years, completed norm-referenced assessments of language and reading ability as well as 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. They demonstrated not only orthographic awareness, but also orthographic sensitivity to varying orthotactic probabilities. This orthographic knowledge translated to the phonological task as the participants' fixations and dwell time on the target images significantly differed according to the orthographic characteristics of the stimulus and target word pairs raw number of fixations and the raw dwell time significantly varied by condition for the phonological task.

Implications – Beginning readers area aware and sensitive to statistical regularities of English orthography. This orthographic knowledge influenced typically developing six- and seven-year-olds' performance on phonemic awareness, but not to the extent seen in older children with and without reading and language impairments. Future studies should

ascertain when orthography has a robust influence on TD beginning readers' phonemic awareness.

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Chapter 1: Introduction

As children learn to read words, 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). Orthographic knowledge is the knowledge of how letters represent sounds in spoken language (Apel, Wolter & Masterson, 2006). Orthographic knowledge refers to the knowledge of the rules and regularities of an orthography, and orthographic sensitivity is the level of attunement to the various rules and regularities. Together, phonological awareness and orthographic knowledge are the two most important early predictors of reading outcomes (Bus & Van IJzendoorn, 1999; Foorman et al., 2016; Mol & Bus, 2011; Treiman, 2006; Ziegler et al., 2010). Studies of advanced readers and adults have demonstrated that orthography does influence phonological processing (Seidenberg & Tanenhaus, 1979; Ziegler & Ferrand, 1998), In the present study, we examined if orthographic knowledge influences phonological processing in typically developing (TD) beginning readers. We also examined how sensitive TD 6- and 7-year-olds are to orthotactic regularities.

Phonological Knowledge

Phonological awareness is a broad umbrella term that includes multiple 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). Phonological awareness is a key element of reading acquisition and decoding not only in English, but also in other alphabetic orthographies (Ziegler et al., 2010). Phonemic awareness, or the ability to identify and manipulate phonemes, is a component of phonological awareness. As one becomes more adept at manipulating phonemes, they begin 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 primes children to attend to sounds, priming the connection of sound to print or the alphabetic principle. Accordingly, phonemic awareness was identified by the National Reading Panel (2000) as one of the 'big five ideas' of reading. Additionally, phonemic awareness helps children notice the regular ways that letters represent sounds in words.

Defining the Parameters of Orthographic Knowledge and Word Reading

<u>Orthographic Knowledge</u>

Orthographic knowledge in alphabetic orthographies is advanced through increasing sensitivity to the sequences and patterns of letters that are governed by positional constraints and regularities (McMurray &McVeigh, 2016). Knowledge of positional constraints has been found to be present in children as early as preschool (Zhang & Treiman, 2021), and the effect of orthographic knowledge on word learning and word recognition has been found as early as the start of second grade (Krasa & Bell, 2021).

Apel, Henbest, and Masterson (2019) emphasize that orthographic knowledge is a two-level construct consisting of lexical orthographic knowledge and sublexical orthographic knowledge. The stored mental representation of known words or word parts (MGRs) constitute lexical orthographic knowledge. Sublexical orthographic knowledge is the knowledge of spelling rules and patterns as well as the knowledge of the rules and patterns for representing a sound with a letter (i.e., the alphabetic principle). Languages vary in the consistency of their mapping of graphemes to phonemes. English is considered a relatively deep orthography because the same letters can be used to represent different sounds, and the same sounds can be represented by different letters. In comparison, Spanish is considered a relatively shallow orthography because the phoneme-grapheme correspondences are much more consistent (Kwok et al., 2017). Examining children's orthographic knowledge is important because of the variations in orthographic consistency in English.

Orthographic Knowledge and Word Reading

Phonemic awareness and the alphabetic principle (sublexical knowledge) are the key building blocks of reading an alphabetic orthography as they enable decoding and spelling. Each time a child decodes an unfamiliar word they initiate a mental representation of the pronunciation, meaning, and spelling of the word; after successfully decoding a word several times a robust 'mental graphemic representation' (MGR) is formed (Apel, 2011). 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 MGRs allow children to quickly access words in future reading and spelling encounters (Ehri, 2005), which helps to not only build fluent and confident reading, but also offers an advantage for continued self-learning

A study by Deacon, Benere, and Castles (2012) examined the extent to which orthographic processing determines reading outcomes by having their 100 participants complete word reading and orthographic processing tasks at Grades 1, 2, and 3. A lexical orthographic processing task asked children to correct the spelling of two orthotactically conceivable alternate spellings (e.g., boal and bowl); to measure sublexical orthographic processing skills, they instructed the children to select the letter-pattern that exemplified the best way to spell a pseudo-word in English (e.g., screigh, scaie, and schism for /skrei/). Their results showed that early word reading significantly predicts later lexical and sublexical orthographic processing ability, making the case that the relationship between orthographic ability and reading is predicated on word reading.

Orthographic Knowledge Development

Emerging evidence suggests that children develop sublexical orthographic knowledge before lexical (Apel, Henbest, & Masterson, 2019). Zhang and Treiman (2021) conducted a study that offers support to the notion that sublexical orthographic knowledge develops prior to lexical orthographic knowledge. They examined preschoolers' sensitivity to how letters combine in words by using 'more wordlike' items (e.g., <CHED>) and 'less wordlike' items created by rearranging the letters from the former condition (e.g., <EHDC>). The preschoolers were shown each item on a card for twenty seconds and were explicitly instructed to look at the letters. Then, the card was removed, and they were asked to write the item in their booklet. Responses were more similar to the target items when the preschoolers were copying 'more wordlike' targets compared to 'less wordlike' targets. Therefore, Zhang and Treiman (2021) show that preschoolers have some knowledge about how letters combine and develop sublexical knowledge as early as four years of age before they have begun formal reading instruction.

Eyetracking has also been used to provide evidence in support of this early presence of orthographic knowledge. Apel and colleagues (2013) used an orthographic fast mapping task in order to examine the effect of words' statistical regularities on TD children's eye movements between the ages of 5 and 6. Their findings showed that children spent more time viewing words with low orthotactic probabilities compared to high orthotactic probabilities and that children correctly spelled more target pseudowords with high orthotactic probabilities; these findings show that the participants were sensitive to orthotactics.

Henbest and Apel (2018) extended the study done by Apel and colleagues (2013) by investigating eye movements at two time points (the fall semester and then the following spring semester) in 5- and 6-year-olds to examine changes in eye movements because of words' statistical properties. Previous studies (Apel, 2010; Apel et al., 2013) showed that preschool and kindergarten children develop some initial MGRs during a shared storybook reading, with this ability improving with age. Therefore, in this study participants were presented with a series of 12 pseudowords embedded in sentences within the context of a story; the words varied in their phonotactic and orthotactic probabilities. The participants were asked to spell and identify the target pseudowords, and their eye movements were recorded during the identification task. They found that there was no effect of statistical regularities on any of the eyetracking parameters used (dwell time, number of fixations, and average fixation duration) at Time 1. However, there was a significant effect of the words' statistical linguistic regularities in the eye movements at Time 2 (approximately 3 months after Time 1). Participants had longer average fixation durations for words with high orthotactic and high phonotactic probabilities compared to words with low orthotactic and high phonotactic probabilities. These results led them to conclude that children's fast mapping skills can improve across a short period of time because they posit that "children are statistical learners when developing orthographic knowledge" (p. 2026), with statistical learning being the ability to distill regularities in the environment. Overall, they found that children's orthographic fast mapping skills are influenced by orthotactic probabilities: words with high orthotactic probabilities were more easily fast-mapped. Their findings also showed that orthographic fast mapping skills are significantly related to success with early literacy skills.

Prior studies show that measuring orthographic knowledge with eyetracking is not only possible, but also helps provide more information regarding the cognitive processing that is facilitating behavioral responses to orthographic taskss (Apel et al., 2013; Henbest & Apel, 2018). However, these studies solely focus on orthographic fast mapping and do not examine the influence of orthography on phonological processing.

Orthographic Influences on Phonemic Awareness

<u>Skilled Readers</u>

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 Tanenhaus (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 (tie/pie) presented either aurally or visually compared to words with different spelling patterns (tie/rye). 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 & Tanenhaus, 1979).

Another study 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 (e.g., /ip/, which may be spelled eap or eep, as in leap and deep) in comparison to words with phonological rimes that could be represented by only one combination of graphemes (e.g., /ʌk/, which may only be spelled uck, as in duck). 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.

Developing Readers

Only a few studies have examined how orthography influences phonemic processing in children. Although evidence suggests that some level of sublexical orthographic knowledge develops before children begin formal reading instruction

(Cassar & Treiman, 1997; Zhang & Treiman, 2021), it is not yet clear when this knowledge influences children's phonological processing. There is some evidence to suggest that these influences of orthographic knowledge on phonemic processing would only appear after some level of reading proficiency has been established. For example, Ziegler and Muneaux (2007) examined orthographic effects on spoken language in French beginning readers (mean age 7.1), advanced readers (mean age 11.4) and readers with dyslexia (the advanced readers and readers with dyslexia were matched for chronological age). The participants were presented with audio recordings of 60 monosyllabic words and 60 nonwords, and they were asked to identify if the auditory stimulus was a real French word. They found that the phonological properties of words influenced spoken word recognition in all three groups (i.e., longer latencies on words with many phonological neighbors), but orthographic effects (i.e., shorter latencies for words with many orthographic neighbors) were observed only in children who were proficient readers. Additionally, the size of the orthographic neighborhood effect varied depending on reading expertise; children with dyslexia had no orthographic neighborhood effects. These results suggest that orthographic knowledge most likely influences children's spoken word recognition only after children are proficient readers.

Castles, Wilson, and Coltheart (2011) 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. Participants were trained in one of two sets of eight letters/sounds. 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 phonemic 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 (e.g., ham). In the second condition, or the silent letter condition, words that rhyme with the control items were presented, but they included a letter that is phonologically obsolete (e.g., lamb). This experiment design measured orthographic intrusion, or when orthographic information influences and interferes with one's performance on phonemic 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.

However, a recent study by Baron and colleagues (2022) which used both behavioral and eyetracking measures has demonstrated that children with persistent dyslexia were influenced by orthography on a phonological awareness task (mean age = 10.7 years, range 8.5 - 13.7 years). While the children with persistent dyslexia showed lower performance overall compared to the TD group and the resolving dyslexics, the influence of orthography was not different between groups. The phonological task used by Baron et al. (2022, in review) is the same task used in the current study. This study suggests that even children who have word reading difficulty that has not been corrected by instruction (i.e., persistent dyslexics) demonstrate influences of orthography on their phonological processing.

The Present Study

The purpose of this study is to examine the relation between orthographic knowledge and phonemic awareness in typically developing 6- and 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- and 7-year- old children experience orthographic interference during a phonological awareness task. We use both behavioral and eyetracking methods to examine these research questions. Eyetracking was used to obtain a more fine-grained analysis of the cognitive processing that occurs before a behavioral response is made providing more information other than accuracy. The current study builds on a similar study conducted using the same eyetracking tasks with children in grades 3-6 who have dyslexia by examining younger children (Baron et al., 2022). This study adds to the existing literature by examining the influence of orthography on phonology at a younger age than previous studies through eyetracking and by combining the examination of orthographic influence on phonology and orthographic sensitivity in children.

Chapter 2: Method

This study involved 6- and-7-year-old children who were typically developing (TD). This study utilized a within-subjects design. The planned sample size was 30 participants. All study procedures were approved by the University of South Carolina Institutional Review Board prior to data collection. We recruited from various avenues including an event for families of students entering kindergarten, flyers posted on social media pages, and community advertisements. Data were collected over three academic years (2018-2020; 2021), with a year-long pause in data collection during the COVID-19 pandemic closures.

Parents or guardians provided informed consent and completed a brief questionnaire regarding demographic information, language background, and their child's medical and educational history. The participants completed two experimental eyetracking 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, which took place in a quiet room at the research lab or in a van designed for eyetracking data collection. Data collection sessions were video- and audio-recorded for offline scoring and reliability checking. 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 were renumerated for their participation.

Participants

We recruited and tested 29 participants; however, norm-referenced results showed that 7 children exhibited reading and language skills that were below normal limits. Thus, the analysis sample includes 22 participants aged 6:2-7:8 (mean = 6:8; *SD* =1:6; 14 males, 8 females). Of these 22 participants, 15 identified as White, 5 identified as Black/African American, 2 participants identified as other. No participants identified as Asian, American Indian, Alaska Native, Native Hawaiian, or Pacific Islander. Two participants identified as Hispanic or Latino. All participants spoke English as their first and only language, had no hearing impairment, or uncorrected vision impairment. Per parent report, there were no concerns about speech, language, and cognitive development.

Materials

Norm-Referenced Assessments

Participants completed several norm-referenced assessments to verify that their word reading and language abilities were within normal limits.

Test of Language and Literacy Skills (TILLS)

Participants 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). For children in this age range, the Identification Core is a composite of scores from three subtests, Vocabulary Awareness, Phonemic Awareness, and Nonword Repetition, which are described below. Participants included in the study achieved a score of 85 or higher on the TILLS Identification Core.

Vocabulary Awareness subtest of the TILLS

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, an item consists of the words plant, water, and cup. The first semantically related pair is plant and water with the potential explanations that plants need water to live. The second semantically related pair is water and cup, and the potential explanation for this choice is that you drink water from a cup. 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 subtest of the TILLS

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 eyetracking phonological processing task.

Nonword Repetition subtest of the TILLS

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.

Letter-Word Identification subtest of Woodcock-Johnson IV

Participants additionally received the Letter-Word Identification subtest of the Woodcock-Johnson, 4th Edition (Woodcock-Johnson IV; Schrank, McGrew, & Mather, 2014). Participants included in the study achieved a standard score of 85 or higher on the Letter-Word Identification subtest. The Letter-Word Identification subtest of the Woodcock-Johnson IV assesses children's word identification skills. Participants are initially asked to identify individual letters and the remaining items require children to read aloud words of increasing difficulty. The test manual reports that median reliability for ages 5-19 is .92.

Woodcock Reading Mastery Test, Third Edition

The first two participants received the Word Identification subtest of the Woodcock Reading Mastery Test, Third Edition (WRMT-III; Woodcock, 2011) in place of the Woodcock Johnson-IV as the materials for the Woodcock Johnson-IV did not arrive in time. Both participants achieved a standard score of 85 of higher on both subtests.

Word Identification subtest of the WRMT-III

The Word Identification subtest of the WRMT-III is an untimed assessment that requires students to read aloud real English words of increasing difficulty. The test manual reports that test-retest reliability for Pre-K to Grade 2 is .95. Spilt-half reliabilty for the form used (Form A) is .98 for age 6 and. 97 for age 7.

Word Attack subtest of the WRMT-III

The Word Attack subtest of the WRMT-III assesses the ability to read nonsense words aloud of increasing difficulty. The test manual reports that test-retest reliability for Pre-K to Grade 2 is .89. Spilt-half reliabilty for the form used (Form A) is .95 for age 6 and. 93 for age 7.

Eye Movement Tasks

Orthographic Processing Task

Participants completed the phonemic awareness task first followed by the orthographic processing task. The orthographic task will be described first in order to establish orthographic sensitivity. This eyetracking task assessed participants' awareness of the constraints and regularities of English orthography. This study design is similar to the orthographic word-likeness task (Stanovich & Siegel, 1994; Treiman, 1993), which is often used to assess what children know about sublexical orthography (Apel, Henbest & Wolter, 2019). In word-likeness measures, children are instructed to select the pseudoword that looks most like a real word from a pair of pseudowords; one pseudoword follows legal orthographic rules whereas the other pseudoword violates orthographic rules.

However, in this study, participants saw four strings of letters in each trial rather than a pair of words. Then they were instructed to "click on the picture that looks most like a real English word" (see Figure 2.1). The task began with two practice items administered with PowerPoint slides in a video format to familiarize participants with the procedure. The first trial was read aloud by the assessor while the audio for the second trial was presented by the computer. The assessor provided corrective feedback for both practice trials. For correct responses, the assessor would say "Yes, that is the word that looks most like a real English word." For incorrect responses, the assessor would say

“That’s not quite right. This one (assessor points) is the one that looks most like a real English word.” Incorrect practice trials were repeated to ensure understanding before moving beginning the task programmed with eyetracking. Participants received feedback on their accuracy for these two practice trials only.

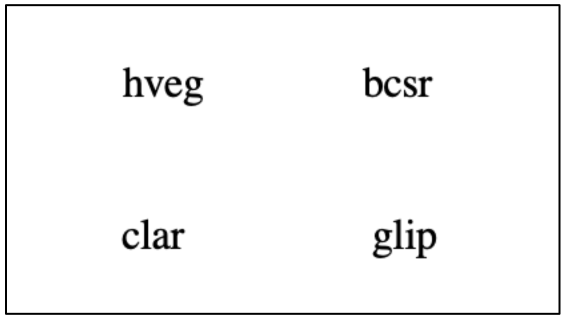

Figure 2.1 Example trial from the orthographic processing task.

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). Both the high orthotactic probability string and the low orthotactic probability string are legal options. Orthotactic probability for the targets and foils was determined from the MCWord Orthographic Wordform Database (Medler & Binder, 2005). The location of the correct trial and foil types were counterbalanced using a Latin Square. Based on previous studies demonstrating that pre-readers have sublexical orthographic awareness, we predicted that participants would have more and longer fixations on legal strings than illegal strings (Apel, Henbest, & Masterson, 2019; Zhang & Treiman, 2021). We were further interested in how sensitive to orthographic constraints and regularities these beginning readers would be, as demonstrated by their preference for high (clar) versus low (glip) probability strings.

Phonemic Awareness Task

The phonemic awareness task assessed participants' ability to identify and compare the final phonemes in spoken words. There were 36 total trials across three conditions. In each trial, participants saw four pictures in a 2x2 grid on a computer screen (see Figure 2.2). First, participants heard a spoken label for each image as the image border was highlighted on the screen. Next, participants were instructed to "click on the picture that ends with the same last sound as [stimulus]". A photo of the stimulus appeared at the top of the screen while the spoken label was played. Participants selected their answer by clicking one of the four options using the computer mouse. 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).

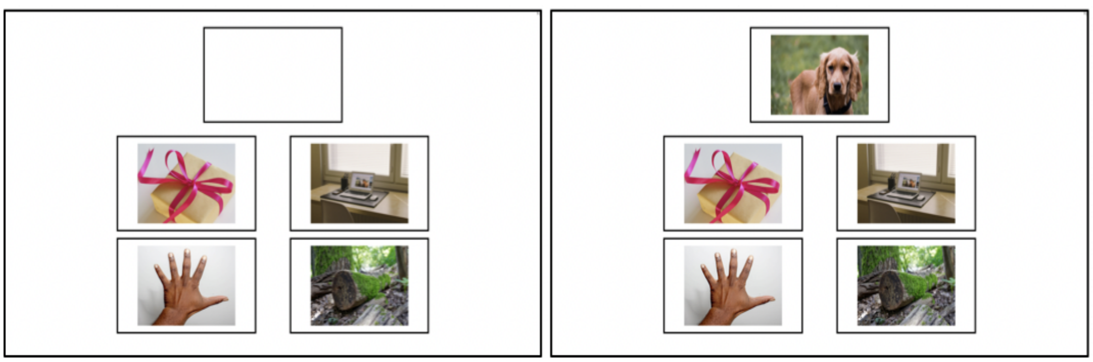

Figure 2.2 Example item from the phonemic awareness task. The left panel shows the beginning of the trial. As participants view the screen, the four pictures are named, left to right, top to bottom: "gift, desk, hand, log. Click on the picture that has the same last sound as…" As the stimulus word is 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.

The order of items, including the stimulus-target condition, was randomized across trials. The correct answer in each trial was the picture that ended with the same phoneme as the stimulus word. The task began with two practice items administered with PowerPoint slides in a video format to familiarize participants with the procedure. The first trial was read aloud by the assessor while the audio for the second trial was presented by the computer. The assessor provided corrective feedback for both practice trials. For correct responses, the assessor would say "Yes, pig and frog have the same last sound of /g/." For incorrect responses, the assessor would say "That's not quite right. The last sound in frog is /g/. Let's listen to the words again: pig, gum, pot, rock. Pig and frog have the same last sound of /g/. So, the correct answer is pig." Incorrect practice trials were repeated to ensure understanding before beginning the task programmed with eyetracking. Participants received feedback on their accuracy for these two practice trials only.

The three conditions that altered orthographic congruency and consistency permitted us to investigate the influence of orthographic knowledge on phonological processing. 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>.

In the congruent-consistent condition (10 trials), the stimulus word and the target word used the same grapheme to represent the final phoneme, and those phoneme-grapheme pairings did not appear in word final position in the other conditions (e.g., Stimulus: mug; Target: tag in Figure 2.3).

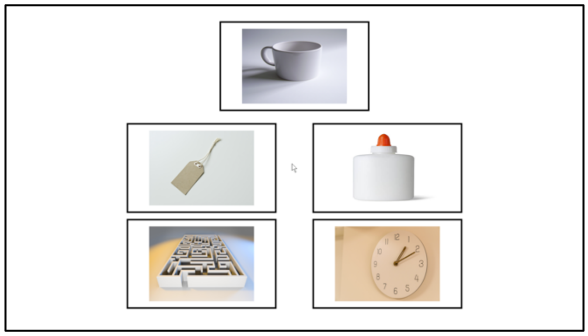

Figure 2.3 Example trial from the congruent consistent condition in the phonemic awareness task.

In the incongruent-inconsistent condition (12 trials), the stimulus word and the target word used different graphemes to represent the same final phoneme (e.g., Stimulus: blocks; Target: fox in Figure 2.4).

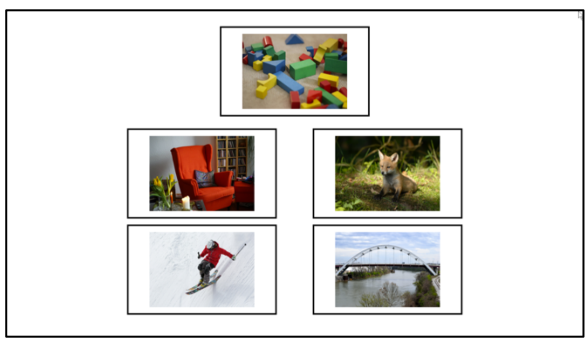

Figure 2.4 Example trial from the incongruent condition in the phonemic awareness task. These words have the same target phonemes as the congruent-inconsistent.

In the congruent-inconsistent condition (14 trials), the stimulus word and target word used the same graphemes to represent the final phoneme within the trial (e.g., Stimulus: bricks; Target: clocks in Figure 2.5), but the same phoneme (/ks/) with different graphemes ("x") appeared in the incongruent-inconsistent condition.

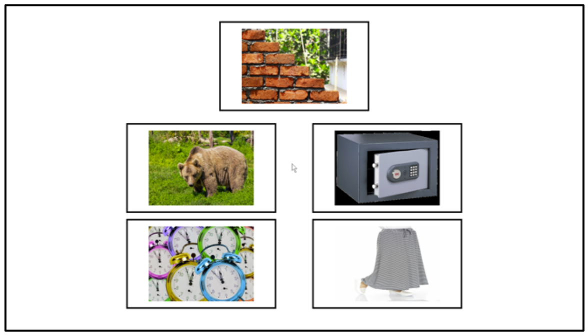

Figure 2.5 Example trial from the congruent-inconsistent condition in the phonemic awareness task. These words have the same target phonemes as the congruent items.

This task is designed to assess if participants' orthographic knowledge interferes with their phonemic awareness 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.

Validation Task

This task was initially created for a study involving children in third through sixth grades (Baron et al., in review). To determine whether six- and seven-year-olds would associate pictures with the same names that we assigned them in the task, we conducted a small validation study involving thirteen 6-and-7-years-olds. The validation task was administered online through the Gorilla Experiment Builder (Anwyl-Irvine, Massonnié, Flitton, Kirkham & Evershed, 2019). In each trial, the participants saw the images and heard the recorded name for the stimulus, target, and three foils. Then they were instructed to "record the name of each picture as it appears". The five images were then presented in random order, and the Gorilla software recorded children's spoken responses, which were scored offline. Accuracy ranged from 38% to 100% across words, with an average of 86.1% (*SD* = 14.9%), and from 64.9% to 100% across participants, with an average of 85.7% (*SD* = 8.2%). Overall, these results indicate that participants could associate the spoken names with the pictured objects from our task and recall them within the trials. These results also reflect the difficulty of the task for 6- and 7-year-old participants.

Eyetracking Apparatus and Procedure

The phonemic 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. The phonemic awareness task was programmed in Experiment Builder software for use with a desktop mounted Eyelink 1000 Plus eye tracker in the remote mode (SR Research, Mississauga, Ontario, Canada). The remote mode was ideal for the age group of this study as it allows participants to make small movements and not have to remain still for the duration of the tasks. Monocular (right eye) movements were recorded continuously using a sampling rate of 500 Hz. The experiment tasks were displayed on an LCD ASUS VG248QE monitor that was 24" (1920 x 1080) screen with 1 ms response time and 144 Hz refresh rate. The screen brightness was set to 60% for optimal pupil dilation during eyetracking. Eyelink's Experiment Builder software controlled the presentation of auditory and visual stimuli and recorded the eye movement data

Participants sat 40cm from the tracker and performed a 9-point multiple line calibration procedure not to exceed 1° of visual angle error prior to beginning the task. Trials would begin when the child fixated on a drift correct target that confirmed correct calibration. If a child moved excessively or had to leave the room for a break, the examiner would have the participant wait for five minutes after re-entry into the testing room to allow their pupils to adjust; the examiner would then perform a new calibration. Trails ended when the participant clicked their mouse on their response choice. Eyetracking measures were extracted from the time between the onset of the stimulus word and the mouse click that would end the trial.

Eyetracking Variables and Inclusion Criteria

Participants' eye movements were recorded to examine their processing from the onset of the stimulus word to the mouse click that ended the trial. For the orthographic task analysis, the participant had to have at least one fixation on each interest area to be included.

The orthographic task considered (1) fixation count for each interest area, or the total number of times each letter string was viewed prior to making a response; (2) dwell time for each interest area, or the total amount of time participants spent viewing an interest area, measured in milliseconds; (3) percent of fixations on each interest area out of all fixations made prior to a response; (4) percent dwell time on correct each interest area prior to making a response.

Inclusion in the phonemic awareness task eyetracking analysis was two-fold including accuracy and trials. Participants had to meet at least 50% accuracy in each condition on the phonemic awareness task to be included (at least 17/36 trials). Additionally, only accurate trials (36 trials total) were included in the eyetracking analysis.

To examine the amount of time participants spent considering the target in each condition, we examined (1) fixation count, or the total number of times an interest area was viewed, and (2) dwell time, or the total amount of time participants spent viewing an interest area, measured in milliseconds. To examine time spent on the target relative to the distractor options for the phonemic task analysis, we also examined (3) percent dwell time on the target versus the stimulus and foils and (4) percent of fixations on the target versus the stimulus and foils.

Procedures

The experimental eyetracking tasks, the TILLS subtests, and the Woodcock Johnson Letter-ID subtest were administered during a session lasting approximately 1 hour and 30 minutes. The vocabulary awareness subtest of the TILLS was administered first to help the participant acclimate to the assessor and the process. Then the phonological eyetracking task was administered, followed by the orthographic eyetracking task. The phonological task was administered first to avoid any sequence/order effects. The session ended with the administration of the TILLS Phonemic Awareness subtest, the TILLS Nonword Repetition subtest, and then the Letter-Word Identification subtest of the Woodcock Johnson-3.

Tasks were administered and scored by graduate students trained by the authors on testing and scoring procedures. 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.

Scoring and Reliability

The norm referenced tests were first scored by the author and then double scored by either a trained graduate student or a doctoral student. Disagreements were resolved by consensus. The orthographic processing and phonemic awareness tasks were scored by Eyelink Data Viewer software.

Statistical Analysis

Multiple analytic procedures were employed to answer the research questions. Within-subject analysis of variance (ANOVA) was used to examine behavioral responses for both tasks, namely, differences in the number of responses of each type (high probability, low probability, illegal string, unpronounceable string) in the orthographic awareness task, and differences in response accuracy between conditions (congruent-consistent, congruent-inconsistent, and incongruent) in the phonemic awareness task.

Eyetracking variables for both tasks were examined using linear mixed effects regression modeling. Prior to analyses, the data were inspected for normality and outliers. All eyetracking variables were positively skewed with the highest levels of skew observed in the raw and percent dwell time variables. There were outliers noted, and data points outside the 95% confidence interval of the mean were Winsorized prior to analysis.

Chapter 3: Results

Descriptive Measures

Descriptive information about the participant sample is provided in Table 3.1, which displays scores on norm-referenced assessments on reading and language. All participants included in analyses scored within normal limits on these assessments.

Table 3.1 Standard scores for norm-referenced assessments

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Age	22	6:11	0:5	6:2	7:8
TILLS Identification Score for 6- and 7-year-olds	22	101.37	9.39	87	120
TILLS Vocabulary Awareness Subtest	22	10.6	2.56	6	15
TILLS Phonemic Awareness Subtest	22	10.10	2.24	7	14
TILLS Nonword Repetition Subtest	22	9.91	2.05	6	14
Woodcock-Johnson IV Letter-Word Identification	20	115.55	14.24	86	131
WRMT-III Word Identification	2*	111.5	9.19	105	118
WRMT-III Word Attack	2*	104.5	4.95	101	108

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

Orthographic Processing Task

Response Choice

Descriptive statistics for response choice on the orthographic awareness task are presented in Table 3.2. Participants chose the high orthotactic strings most often (X = 10.95, SD = 13.50) followed by the low orthotactic string (X = 4.91, SD = 1.95), and they rarely chose illegal (X = 0.95, SD = 1.81) or unpronounceable (X = 1.18, SD = 1.82) strings. These data were analyzed with a repeated measures ANOVA, which showed a very large effect of nonword type on response choice. F (3, 63) = 63.62, p < .001, partial eta squared = .752. Planned follow up comparisons indicated significant differences between all word types (all p <.001) except the illegal and unpronounceable strings (p = .381).

Table 3.2 Descriptive statistics for response choice on orthographic task

Condition	Mean	SD
High orthotactic probability	10.95	13.50
Low orthotactic probability	4.91	1.95
Illegal string	0.95	1.81
Unpronounceable string	1.18	1.82

Eyetracking Variables

Eyetracking analyses included 22 participants (all participants had at least one fixation on each interest area in each trial). The linear mixed effects regression models revealed a significant main effect of string type for all eyetracking variables, including number of fixations, dwell time, percent fixations on target, percent dwell time on target.

Raw Fixations on the Target. Figure 3.1 displays the distribution of raw fixations on the target for each letter string type in the orthographic task with error bars representing the standard deviation. Table 3.3 reports the results from the linear mixed effects regression models for the total amount of fixations on each letter string. The high orthotactic probability strings had the highest number of fixations, and all string types had significantly less fixations (p = <0.001) compared to the high orthotactic string type. The low string also had significantly more raw fixations when compared to the illegal string (p = <0.001) and the unpronounceable string (p = <0.001), whereas the number of raw fixations for the illegal and unpronounceable strings did not differ (p = 0.300).

Table 3.3 Model results for fixations by interest area on orthographic task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
High orthotactic string as reference condition			
(Intercept)	2.35	2.13 – 2.58	**<0.001**
High vs. Low	-0.37	-0.57 – -0.18	**<0.001**
High vs Illegal	-0.78	-0.97 – -0.59	**<0.001**
High vs. Unpronounceable	-0.88	-1.08 – -0.69z	**<0.001**
Low orthotactic string as reference condition			
(Intercept)	1.98	1.76 – 2.20	**<0.001**
Low vs. Illegal	-0.41	-0.60 – -0.22	**<0.001**
Low vs. Unpronounceable	-0.51	-0.70 – -0.32	**<0.001**
Illegal string as reference condition			
(Intercept)	1.57	1.35 – 1.80	**<0.001**
Illegal vs. unpronounceable	-0.10	-0.29 – -0.09	0.300

Random Effects	
σ^2	1.90
$\tau_{00\ participant\_id}$	0.18
ICC	0.09
$N_{participant\_id}$	22

Marginal R^2 / Conditional R^2 = 0.056/0.138

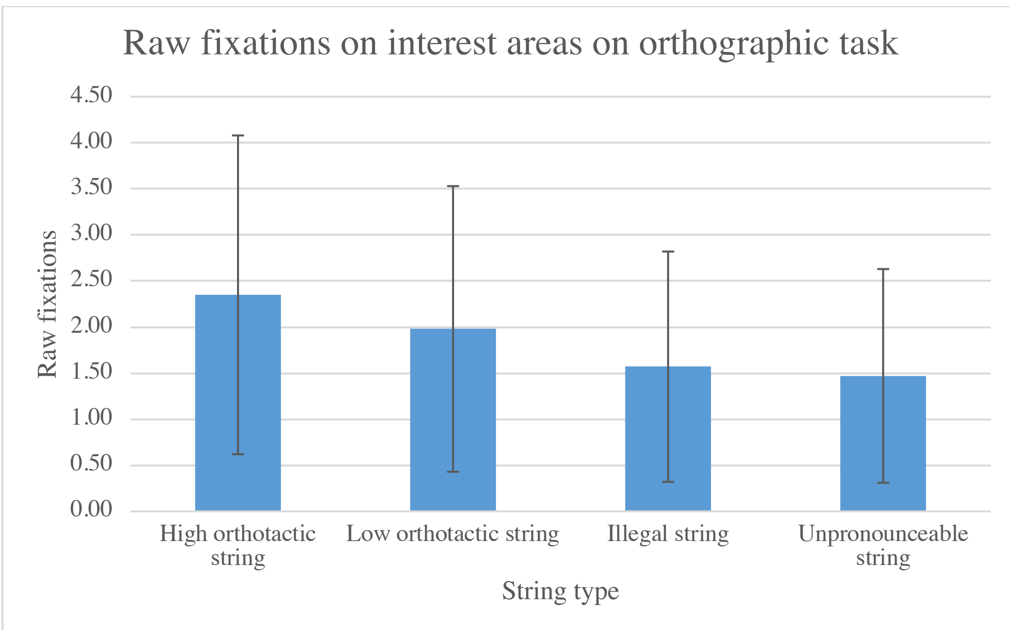

Figure 3.1 Raw fixations on interest areas on orthographic task

Raw Dwell Time on the Target. Figure 3.2 displays the distribution of raw dwell time on the target for each letter string type in the orthographic task with error bars representing the standard deviation. Results from the linear mixed effects regression models show that all string types had significantly less dwell time (p = <0.001) compared to the high orthotactic string type (Table 3.4). The high orthotactic string had a dwell time of 2113.75 ms, the low orthotactic string had the second highest dwell time (b = -574.98) when compared to the high string, the illegal string had the third lowest dwell time (b = -

1249.98) compared to the high string, and the unpronounceable string had the lowest dwell time compared to the high string (b = -1304.91). The illegal and unpronounceable strings had significantly shorter dwell times ($p = <0.001$) when compared to the low string, and they did not differ from each other ($p = 0.578$).

Table 3.4 Model results for raw dwell time by interest area on orthographic task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
High orthotactic string as reference condition			
(Intercept)	2113.75	1815.16 – 2412.33	**<0.001**
High vs. Low	-574.98	-768.40 – -348.57	**<0.001**
High vs Illegal	-1249.98	-1443.40 – -1056.56	**<0.001**
High vs. Unpronounceable	-1304.91	-498.33 – -1111.49	**<0.001**
Low orthotactic string as reference condition			
(Intercept)	1538.76	1240.18 – 1837.35	**<0.001**
Low vs. Illegal	-674.99	-868.41 – -481.58	**<0.001**
Low vs. Unpronounceable	-729.92	-923.34 – -536.51	**<0.001**
Illegal string as reference condition			
(Intercept)	863.77	565.18 – 1162.36	**<0.001**
Illegal vs. unpronounceable	-54.93	-248.35 – 138.49	0.578
Random Effects			
σ^2	1925293.70		
$\tau_{00\ participant\_id}$	402838.65		
ICC	0.17		
$N_{participant\_id}$	22		

Marginal R^2 / Conditional R^2 = 0.110/0.264

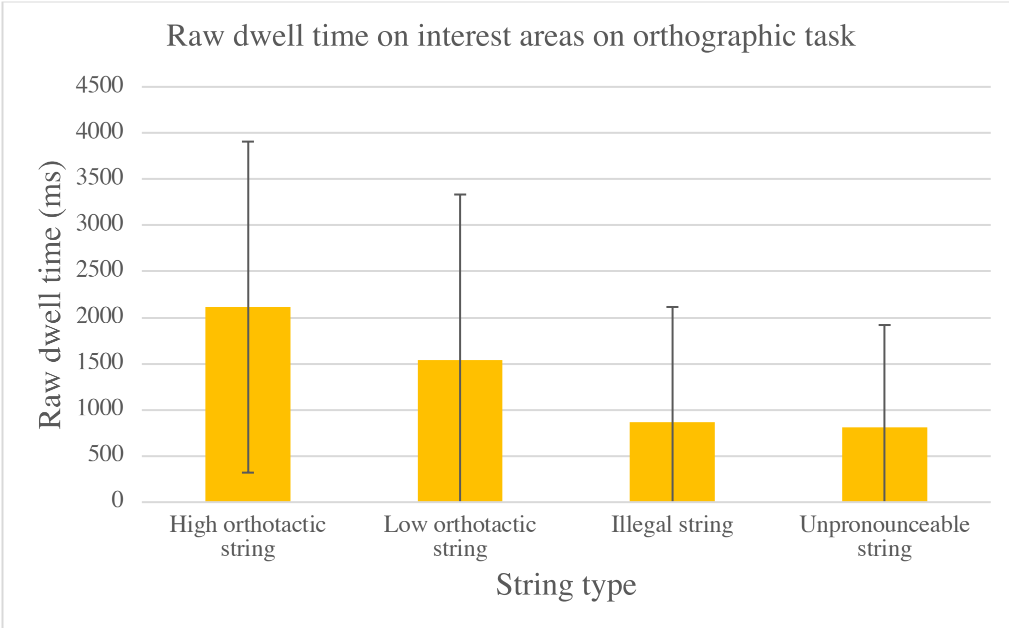

Figure 3.2 Raw dwell time on interest areas on orthographic task

Percent Fixations on the Target. Figure 3.3 displays the distribution of percent fixations on the target for each letter string type in the orthographic task with standard deviation error bars. Table 3.5 reports the results of the linear mixed effects regression models for percent fixations on the target. There were significant differences in the percent fixations on the target in the high string (p = <0.001), with 21% of total fixations on the target in the high string type (b = 0.21). There were 4% less fixations on the target for the low string versus the high string (b = -0.04), 7% less fixations on the target for the illegal string versus the high string (b = -0.07), and 9% less fixations on the unpronounceable string compared to the high string (b = -0.09). These differences in percent fixation on the target between the high string and the other three string types were all significant (p = <0.001). There were significantly lower percent fixations on the target for the illegal (p = <0.001) and unpronounceable strings (p = <0.001) compared to the low string, and there were no significant differences between illegal and unpronounceable strings (p = 0.147).

Table 3.5 Model results for percent fixations by interest area on orthographic task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
High orthotactic string as reference condition			
(Intercept)	0.21	0.20 - 0.23	**<0.001**
High vs. Low	-0.04	-0.06 – -0.03	**<0.001**
High vs Illegal	-0.07	-0.09 – -0.06	**<0.001**
High vs. Unpronounceable	-0.09	-0.10 – -0.07	**<0.001**
Low orthotactic string as reference condition			
(Intercept)	0.17	0.16 – 0.19	**<0.001**
Low vs. Illegal	-0.03	-0.05 – -0.02	**<0.001**
Low vs. Unpronounceable	-0.05	-0.06 – -0.03	**<0.001**
Illegal string as reference condition			
(Intercept)	0.14	0.13 – 0.15	**<0.001**
Illegal vs. unpronounceable	-0.01	-0.03 – 0.00	0.147
Random Effects			
σ^2	0.01		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.04		
$N_{participant\_id}$	22		

Marginal R^2 / Conditional R^2 = 0.085/0.124

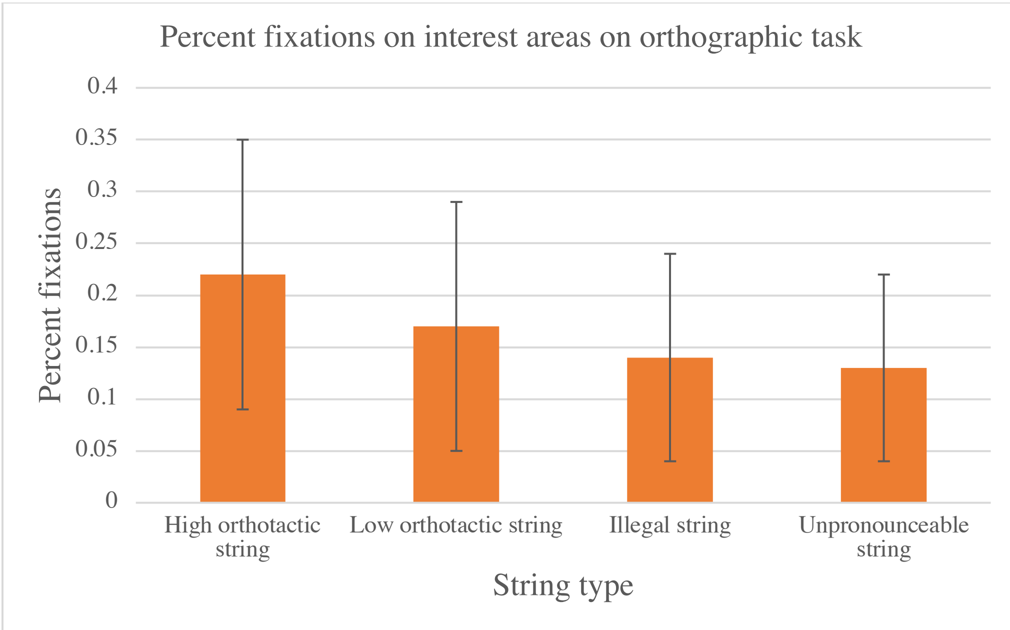

Figure 3.3 Percent fixations on interest areas on orthographic task

Percent Dwell Time on the Target. Figure 3.4 displays the distribution of percent dwell time on the target for each letter string type in the orthographic task with standard deviation error bars. Table 3.6 reports the results of the linear mixed effects regression models for percent dwell time on the target. There were significant differences in the percent dwell time on the target in the high string (p = <0.001), with 34% of total dwell time on the target for the high string (b = 0.34). There was 13% less dwell time on the target in the low string versus the high string (b = -0.13), 23% less dwell time on the target in the illegal string versus the high string (b = -0.23), and 23% less dwell time on the unpronounceable string compared to the high string (b = -0.23). These differences between the high string and the other three string types were all significant (p = <0.001). There were also significantly lower percent dwell times on the target for the illegal (p = <0.001) and unpronounceable strings (p = <0.001) compared to the low string, but there were no significant differences between illegal and unpronounceable strings (p = 0.661).

Table 3.6 Model results for percent dwell time by interest area on orthographic task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
High orthotactic string as reference condition			
(Intercept)	0.34	0.32 - 0.36	**<0.001**
High vs. Low	-0.13	-0.15 – -0.10	**<0.001**
High vs Illegal	-0.23	-0.25 – -0.20	**<0.001**
High vs. Unpronounceable	-0.23	-0.26 – -0.21	**<0.001**
Low orthotactic string as reference condition			
(Intercept)	0.22	0.20 – 0.24	**<0.001**
Low vs. Illegal	-0.10	-0.13 – -0.08	**<0.001**
Low vs. Unpronounceable	-0.11	-0.13 – -0.08	**<0.001**
Illegal string as reference condition			
(Intercept)	0.11	0.09 – 0.13	**<0.001**
Illegal vs. unpronounceable	-0.01	-0.03 – 0.02	0.661
Random Effects			
σ^2	0.03		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.01		
$N_{participant\_id}$	22		

Marginal R^2 / Conditional R^2 = 0.231/0.242

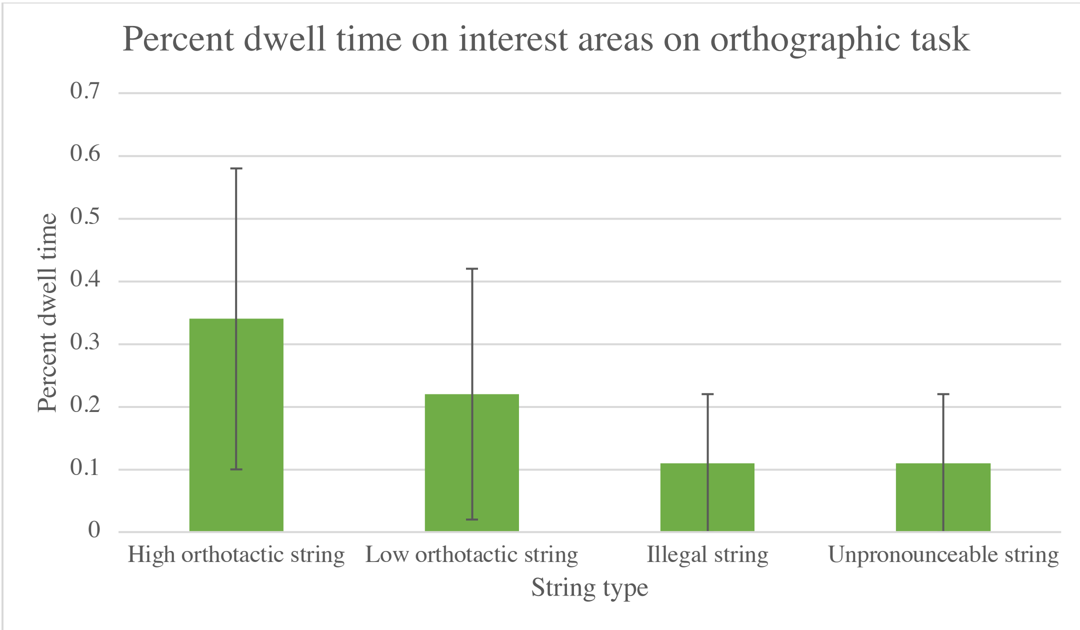

Figure 3.4 Percent dwell time on interest areas on orthographic task

Participants were able to discern the difference between the low orthotactic string and the illegal and unpronounceable string; they had less fixations (p = <0.001), shorter dwell times (p = <0.001), lower percent fixations (p = <0.001), and lower percent dwell times (p = <0.001) on the illegal and unpronounceable strings compared to the low string. Participants had significant differences between the high string type and the other three string types for raw number of fixations (p = <0.001), raw dwell time (p = <0.001), percent fixations (p = <0.001), and percent dwell time (p = <0.001). This reflects orthographic sensitivity not only to the difference between legal (high and low strings) and illegal strings (illegal and unpronounceable strings), but also sensitivity to the variations in orthotactic probability (high versus low). Response choice accuracy showed a large effect of nonword type (p = <0.001); when taken together with the eyetracking results, the data reflects participants awareness of the constraints and rules of English orthography.

Phonemic Awareness Task

Accuracy

Descriptive statistics for accuracy on the phonemic awareness task are presented by condition in Table 3.7. As shown in Table 3.7, the mean accuracy for the CC condition was highest (*X* = 70.9%, *SD* = 23.3%), followed by CI (*X* = 66.9%, *SD* = 23.8%), followed by IN (*X* = 61.4%, *SD* = 23.1%). Although the accuracy rates suggest the task was difficult for participants, accuracy was well above chance (25%) across all conditions. These data were analyzed with a repeated measures ANOVA; the main effect of condition was marginal, but nonsignificant F (2, 42) = 2.72, p = .077, partial eta squared = .115. Planned follow up comparisons indicated no difference between the CC and CI conditions (p = .306) or the CI and IN conditions (p = .142), and a marginal difference between the CC and IN conditions (p = .059).

Table 3.7 Descriptive statistics for accuracy on phonemic awareness task

Condition	**Mean**	**SD**
Congruent-Consistent	70.91	23.28
Congruent-Inconsistent	66.88	23.78
Incongruent-Inconsistent	61.36	23.08

Eyetracking Variables

Eyetracking analyses included 17 participants who had achieved at least 50% accuracy in each condition on the phonemic awareness to be included (at least 17/36 trials). Only trials with correct responses were included in the analyses. Linear mixed effects regression models examined the main effect of condition for all the eyetracking variables:

raw fixations on target, raw dwell time on target, percent fixations on target, and percent dwell time on target.

Raw Fixations on the Target. Figure 3.5 shows the distribution of raw fixations on the target for each condition in the phonemic awareness task with error bars representing standard deviations. Table 3.8 reports the results of the linear mixed effects regression models for raw number of fixations on the target. Significant differences in the raw fixations on the CC condition (p = <0.001) were detected as well as significant condition differences between the CC condition and the IN condition (p = 0.007). The IN condition had more fixations (b = 1.09) than the CC condition (b = 5.86). There were no significant differences for the CI condition compared to the CC condition (p = 0.838). A significant difference was also found between the raw fixations on the target in the CI condition versus the IN condition (p = 0.031) as the CI condition had 0.94 more fixations on the target than the IN condition (b = 0.94).

Table 3.8 Model results for raw fixations on the target on phonemic awareness task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
CC condition as referent condition			
(Intercept)	5.86	4.98 – 6.73	**<0.001**
CC vs. CI	0.08	-0.67 – 0.82	0.838
CC vs. IN	1.09	0.30 – 1.89	**0.007**
<u>Random Effects</u>			
σ^2	11.07		
$\tau_{00\ \text{participant\_id}}$	1.94		
ICCz	0.15		
$N_{\text{participant\_id}}$	17		

Marginal R^2 / Conditional R^2 = 0.018/0.165			
CI condition as referent condition			
(Intercept)	6.11	5.19 – 7.04	**<0.001**
CI vs. IN	0.94	0.09 – 1.80	**0.031**
<u>Random Effects</u>			
σ^2	15.22		
$\tau_{00\ participant\_id}$	2.35		
ICC	0.13		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.012/0.145			

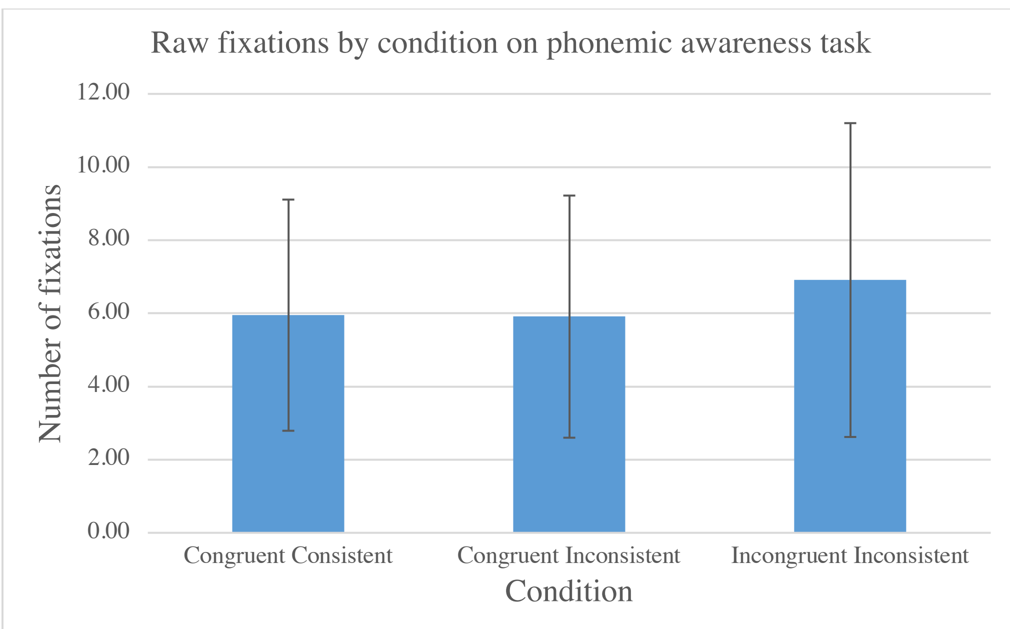

Figure 3.5 Raw fixations by condition on phonemic awareness task

Raw Dwell Time on the Target. Figure 3.6 displays the distribution of dwell time on the target for each condition in the phonemic awareness task with error bars representing standard deviations. Table 3.9 reports the results of the linear mixed effects regression models for the total amount of time spent looking at the target. Significant differences in the CC condition (p = <0.001) were detected as well as between the CC condition and the CI condition (p = 0.049) and the CC condition and the IN condition (p = 0.001). There was not a significant difference between the dwell time on the target in the CI condition compared to the IN condition (p = 0.128). When compared to the CC condition, the longest dwell time was for the IN condition (b = 706.21), with the CI condition having the second longest dwell time (b = 375.56).

Table 3.9 Model results for raw dwell time on the target on phonemic awareness task

Parameter	**Estimates (b)**	**Confidence Interval**	**p-value**
CC condition as referent condition			
(Intercept)	2551.91	2084.27 – 3019.55	**<0.001**
CC vs. CI	375. 56	1.51 – 749.61	**0.049**
CC vs. IN	706.21	308.88 – 1103.54	**0.001**
Random Effects			
σ^2	2787446.21		
$\tau_{00\ participant\_id}$	602932.91		
ICC	0.18		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.022/0.196			
CI condition as referent condition			
(Intercept)	2994.72	2496.64 – 3492.81	**<0.001**
CI vs. IN	343.90	-98.97 – 786.77	0.128
Random Effects			
σ^2	4055195.26		
$\tau_{00\ participant\_id}$	712973.87		

ICC	0.15
$N_{participant\_id}$	17
Marginal R^2 / Conditional R^2 = 0.015/0.162	

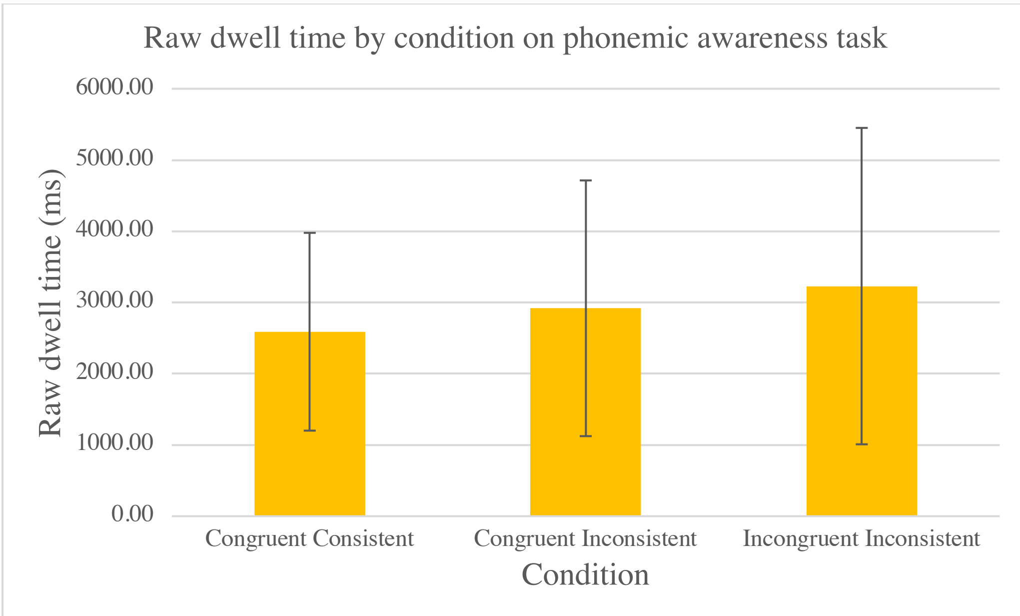

Figure 3.6 Raw dwell time by condition on phonemic awareness task

Percent Fixations on the Target. Figure 3.7 shows the distribution of percent fixations on the target for each condition in the phonemic awareness task with error bars representing the standard deviation. Table 3.10 reports the results of the linear mixed effects regression models for percent fixations on the target. There were no significant differences on percent fixations on the target found between the CC condition versus the CI condition (p = 0.091), the CC condition versus the IN condition (p = 0.429), and the CI condition versus the IN condition (p = 0.410). However, there was a significant difference in the percent fixations on the target in the CC condition (p = <0.001).

Table 3.10 Model results for percent fixations on the target in phonemic awareness task

Parameter	**Estimate (b)**	**Confidence Interval**	**p-value**
CC as referent condition			
(Intercept)	0.30	0.28 – 0.33	**<0.001**
CC vs. CI	-0.02	-0.05 – 0.00	0. 091
CC vs. IN	-0.01	-0.04 – 0.02	0.429
Random Effects			
σ^2	0.02		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.07		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.006/0.072			
CI as referent condition			
(Intercept)	0.28	0.25 – 0.30	**<0.001**
CI vs. IN	0.01	-0.02 – 0.04	0.410
Random Effects			
σ^2	0.02		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.06		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.005/0.063			

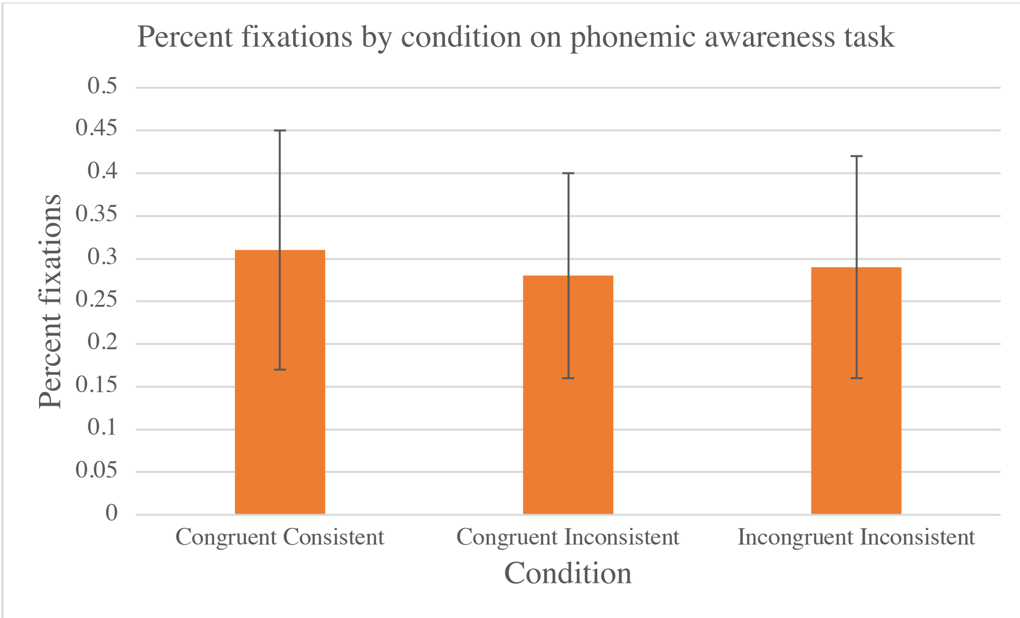

Figure 3.7 Percent fixations by condition on phonemic awareness task

Percent Dwell Time on the Target. Figure 3.8 displays the distribution of percent dwell time on the target for each condition in the phonemic awareness task with error bars representing the standard deviation. Table 3.11 reports the results of linear mixed effects regression models for percent of dwell time on the target. Across conditions, participants spent a significantly longer percent of dwell time on the target in the CC condition (p = <0.001). No significant differences were found in the percent dwell time on target between the CC condition and CI condition ($p = 0.227$), between the CC condition and IN condition ($p = 0.222$), and between the CI condition and the IN condition ($p = 0.871$).

Table 3.11 Model results for percent dwell time on the target in phonemic awareness task

Parameter	**Estimate (b)**	**Confidence Interval**	**p-value**
CC as referent condition			
(Intercept)	0.33	0.30 – 0.36	**<0.001**
CC vs. CI	-0.02	-0.05 – 0.01	0.227
CC vs. IN	-0.02	-0.05 – 0.01	0.222
Random Effects			
σ^2	0.02		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.07		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.004/0.078			
CI as referent condition			
(Intercept)	0.28	0.25 – 0.30	**<0.001**
CI vs. IN	-0.00	-0.03 – 0.03	0.871
Random Effects			
σ^2	0.02		
$\tau_{00\ participant\_id}$	0.00		
ICC	0.06		
$N_{participant\_id}$	17		
Marginal R^2 / Conditional R^2 = 0.005/0.063			

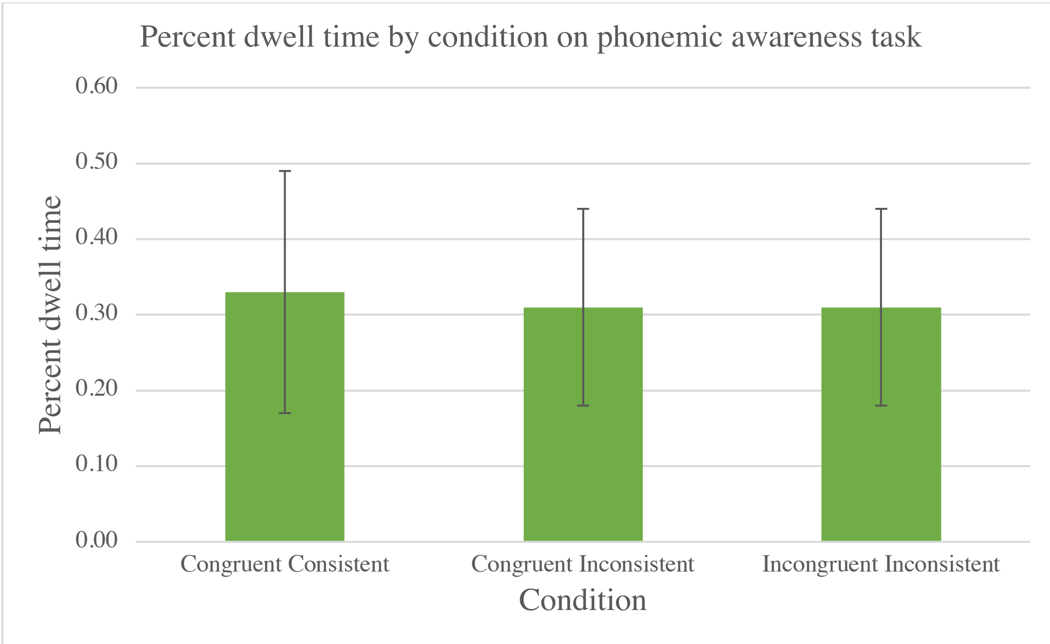

Figure 3.8 Percent dwell time by condition on phonemic awareness task

There were no significant differences in accuracy across conditions, but the accuracy data does demonstrate despite the difficulty of the task, participants' response rates were significantly higher than chance (25%) in all three conditions. The raw number of fixations and the raw dwell time significantly varied by condition. Participants had significantly more fixations on the target when the orthography was congruent (CC and CI) than when it was incongruent (IN) and longer dwell times on the target in the CC condition than the CI and IN conditions. Overall, there were no significant differences in the percent fixation and percent dwell time on the target, which suggests that while raw number of fixations and dwell time significantly varied by condition, the percentage of fixations/dwell time on the target did not vary between conditions.

Chapter 4: Discussion

The present study was designed to answer two questions: 1) how sensitive are TD beginning readers to orthographic probabilities, and 2) do words' orthographic properties influence phonemic awareness in TD beginning readers.

Orthographic Sensitivity of Beginning Readers

Orthographic constraints allow readers to differentiate between legal and illegal letter strings. If beginning readers are aware of orthographic constraints and are sensitive to orthographic regularities including co-occurring letter patterns in varying word positions (orthotactic probabilities), then beginning readers 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. Our findings demonstrate that typically developing 6- and 7-year-old children show awareness of and sensitivity to orthotactic probabilities.

Participants had significantly more fixations and longer fixations on legal strings (high and low probability strings) than illegal strings (illegal and unpronounceable). When considering the percent fixations on the target, participants also spent significantly more percent of fixations and dwell time looking at legal vs illegal strings. These findings show that TD 6- and 7-year-olds have orthographic awareness and are able to accurately discern legal versus illegal letter strings.

Additionally, the results showed that participants were sensitive to orthotactic probabilities. Both the high condition and the low condition were legal options in the eyetracking task as they could both be real English words based on orthographic rules; the difference in the two conditions is that the high condition was more orthotactically probable compared to the low condition. Participants were accurate in their discernment of orthotactic probability. There was a significant difference in the dwell time and number of fixations between the letter strings that had a higher orthotactic probability and the letter strings with a lower orthotactic probability. This shows that participants are not only aware of orthotactic constraints of English orthography, but they are also sensitive to statistical regularities.

Effects of Orthographic Processing on Phonological Task

The eyetracking data from this study reveals that TD 6- and 7-year-olds are aware of and sensitive to orthographic probabilities. Our next research question looked to see if this orthographic knowledge influenced phonemic awareness. We predicted that if orthography influences phonemic awareness, the congruent-consistent condition would require the least amount of cognitive effort (e.g., mug, tag), the congruent-inconsistent condition would require moderate cognitive effort (e.g., clocks, bricks), and the incongruent condition would require the most cognitive effort (e.g., blocks, fox). In other words, as the conditions move from congruent to incongruent and consistent to inconsistent, we expected orthography to have a stronger influence as reflected by a decrease in accuracy, an increase in overall processing time (i.e., more raw fixations or longer raw dwell time), and reduced discrimination between targets and foils on the eye movement variables (i.e., lower percentage of fixations or dwell time on the target).

The mean accuracy values matched our predictions, with higher accuracy on the congruent-consistent condition compared to the two other conditions. Participants were also more accurate on the congruent-inconsistent condition than the incongruent-inconsistent condition. However, these differences between conditions were not statistically significant. Therefore, while the orthographic processing task revealed that the participants were sensitive to orthographic constraints and regularities, this fine-grained orthographic knowledge did not significantly influence their accuracy in the phonemic awareness task. However, eyetracking analyses revealed significant differences between the phonological task conditions.

Significant differences were found for raw fixations on the target for the CC condition versus the IN condition ($p = 0.007$). The higher number of fixations on the IN condition shows that fixations on the target interest area were greatest in this condition during the phonemic awareness task. This same effect was observed for raw dwell time on the target; significant differences were detected for the CC condition versus the CI condition ($p = 0.049$) and for the CC condition versus the IN condition ($p = 0.001$). The longer dwell times on the target and the higher number of raw fixations on the target in the IN condition and the CI condition likely reflect greater difficulty for these trials, which required more overall processing time to provide an accurate response.

The linear mixed effects regression models did not show a significant difference in the percent fixation on the target on the target between the CC condition and the CI condition ($p = 0.091$) or the IN condition ($p = 0.429$). Additionally, the linear mixed effects regression models did not show a significant difference in percent dwell time on the target between the CC condition and the CI condition ($p = 0.227$) or the IN condition ($p = 0.222$). Thus, while the total processing time and number of looks varied between conditions, participants allocated the same percentage of looks and dwell time to the target vs. foils across all conditions.

We predicted that orthography's influence on phonemic awareness could be reflected by either a decrease in accuracy or by a reduction in eye movement efficiency as the conditions moved from congruent to incongruent and from consistent to inconsistent. The accuracy analyses did not reveal significant differences as the conditions increased in difficulty. We anticipated that eye movement efficiency would be reduced as conditions became inconsistent and incongruent which would be demonstrated by increased processing time or by a lower percent fixations or lower percent of dwell time on the target. While the eyetracking analyses did capture significant differences in processing across conditions reflected by the raw number of fixations and the length of dwell time on the target, there were no significant differences for the percent dwell time or percent fixations on the target across conditions.

Krasa & Bell (2021) looked at the association between orthotactic sensitivity and fluency in silent word reading in students in kindergarten through Grade 5. The orthotactic sensitivity test (OST) was used, which contained 30 pairs of pronounceable pseudowords; participants were instructed to circle the pseudoword in each pair that looked more like a word. Krasa and Bell (2021) found that orthotactic sensitivity improved rapidly from kindergarten to Grade 2 for children with at least average decoding fluency and that orthotactic sensitivity becomes evident in its effect on word learning and recognition around start of Grade 2. They additionally found a strong correlation between orthotactic sensitivity and silent word-reading fluency.

Another study by Baron, Ehrhorn, Shlanta, Ashby, Bell, and Adlof (2022, in review) that used the same eyetracking tasks as this study found that children in grades 3-6 who have dyslexia (as well as TD children) show strong effects of orthography in their phonemic awareness performance. Therefore, this generates the question of when orthographic knowledge influences phonemic awareness in TD children. Older school-aged children experience orthographic influence on phonemic awareness tasks, even when they have dyslexia. Therefore, the current study and the study by Baron et al. (2022) bookend the developmental window for when orthographic knowledge influences phonological processing.

Limitations and Future Research

The current sample size is smaller than planned ($N = 22$) but this study used a within-subject design. Although there was adequate statistical power to detect effects across behavioral and eye movement measures in the orthographic task, the phonological task was more difficult for participants, and there was insufficient power to detect significant effects in accuracy. It is possible that an easier task design, a higher number of items, or a higher number of participants would have yielded significant differences in conditions in the accuracy of the phonological task. Higher accuracy levels would have allowed more items to enter into the eye movement analyses as well.

One advantage of using this task is that it allows for a developmental comparison. Baron and colleagues (2022) conducted a study using the same eyetracking tasks with older students with and without reading impairments. This study showed that children with a wide range of word reading abilities (TD, resolved dyslexia, persistent dyslexia) appeared to be influenced by orthography on phonemic awareness tasks. A future study could use an individual differences analysis to examine at what point orthographic knowledge begins to influence phonological processing in TD children as well as in children with reading and language impairments.

This research would help practitioners in multiple ways. First, it would help clarify the role of orthographic knowledge in phonological processing, which could improve evidence-based best practices for teaching phonological awareness. Additionally, establishing expectations and benchmarks for orthographic influence on phonological processing in typically developing children enables comparison to discern when children are missing this benchmark. This could allow for more sensitive tools to screen and evaluate children for dyslexia and developmental language disorder. Currently there are many discussions occurring regarding increasing children's phonological, and therefore, phonemic awareness (Clemens et al., 2021). If orthographic consistency and congruency effects are positively correlated with word reading ability in typically developing children and those with disorders, this would lend support for explicit interventions focused on orthographic skills in children with reading and language disorders. Understanding when orthography influences phonological processing in all children would work to improve how children with reading and language disorders are identified, evaluated, and treated.

Conclusion

Taken together, the data indicate that TD 6- and 7-year-old children are highly sensitive to both orthographic constraints and regularities. We also observed that orthography influences their performance on phonemic awareness, albeit in a less robust manner than has been observed in older children. The current study provides a proof-of-concept for the use of eyetracking to provide a more sensitive measure of orthographic and phonemic awareness processing compared to standard measures that rely on behavioral accuracy. More research is warranted to discern when orthography begins to have a robust influence on phonemic awareness in TD beginning readers.

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