

Research Article

Integrating Orthographic and Phonological Knowledge in Early Readers: Implicit and Explicit Knowledge

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Children develop some orthographic knowledge before learning to read. In some contexts phonological knowledge can scaffold orthographic understanding, but in others, phonological knowledge must be ignored in favor of orthographic knowledge. The current study examines the development of orthographic knowledge as it interacts with phonological knowledge in early readers. Forty-five Kindergarten students were presented with two different nonwords on screen and their gaze was tracked. In the first task, they were asked to choose the best “word,” and in the second task they were asked to choose the best “word” for a specific pronunciation, thereby requiring phonological decoding of the stimuli. Our findings indicate that early readers show explicit awareness of some orthographic conventions and implicit awareness of others, but they only showed implicit awareness when they did not have to additionally decode the stimuli. These results suggest that early orthographic knowledge may be fragile and easily masked by phonological knowledge.

1. Introduction

What children know about written words as they begin school predicts their early literacy development and long term academic success (for review see [1]). Therefore, how young children develop this knowledge about words has been a key area of developmental literacy research. In particular, readers must incorporate three key elements into their knowledge of a written word: orthography (spelling), phonology (pronunciation), and semantics (meaning) (e.g., [2–6]). Knowledge of each element is insufficient for reading; all of these elements must be fully integrated into one lexical representation such that activation of one element leads to the successful retrieval of the other elements from memory [7, 8]. In short, for reading success, children must know the spelling of the word “cat,” the pronunciation /kæt/, and the meaning (furry creature), but, just as importantly, those three elements must be closely integrated so that when children see the word “cat” the pronunciation and meaning are automatically associated with it. The goal of the current study is to examine the development of orthographic knowledge as it interacts with phonological knowledge in early readers.

Complicating this issue is that both orthography and phonology operate on multiple levels. Orthographic knowledge includes “both knowledge of the actual spelling of particular words and higher level conceptual skills, such as the recognition of the properties of words and sequences and typical positions of letters in English” [9, p. 250]. That is, orthographic knowledge has two elements—both lexicalized knowledge of individual word representations (i.e., knowing that “llama” is the written code for the spoken word /lama/) and generalized knowledge of patterns across words (i.e., knowing that words do not typically begin with a doubled letter). Similarly phonological knowledge includes multiple levels of understanding of the sounds of language that develop along different timelines [10, 11].

Historically, research has focused on lexicalized orthographic knowledge, and therefore it has often been considered as a relatively later developing knowledge system, emerging only after children receive direct instruction in written language, usually in the Kindergarten or early elementary years [12, 13]. Other types of symbolic knowledge—logographic, iconic, and perceptual knowledge systems—were typically considered to begin developing in some form at birth [14].

Phonological knowledge—the understanding of the sounds of a language—in particular has long been considered to develop even before birth [15, 16]. Importantly, many researchers have historically considered orthographic knowledge to stem directly from phonological knowledge, such that researchers once considered early orthographic representation (i.e., spellings) as random until it became linked with early phonological knowledge [13].

When considering more generalized orthographic knowledge, however, some researchers have long argued that preschool aged children demonstrate early knowledge in their early spelling [17] but that it may look random, because it may not be related to their phonological knowledge [18]. In this way, children may have an understanding of the general rules of written language that is distinct from their understanding of oral language [19, 20]. Within the past decade, this research has been expanded to show that children may be sensitive to the statistical patterns in print. That is, children may be able to extrapolate rules of spelling and orthography implicitly by unconsciously noting common patterns in the written language they encounter [21], thereby implicitly learning orthographic information through routine exposure before any direct instruction [22]. Accordingly, statistical probability seems to be a significant influence on children's spelling development (e.g., [23, 24]) and other visual patterns [25–27].

This type of implicit learning from the environment has been demonstrated with other types of learning. In particular, phonological development has also been shown to occur through statistical learning with infants as young as newborns learning some phonological information through brief indirect exposure (e.g., [28–31]). Taken together, this research suggests that an early form of orthographic awareness is learned distinctly from phonological awareness, though potentially through similar cognitive processes.

Although the above studies suggest parallel development of orthographic and phonological knowledge, additional studies have suggested that once children begin to read independently, children's phonological skill is directly related to the development of orthographic knowledge. The *self-teaching* hypothesis [32] states that the process of decoding gives children the opportunity to process the orthographic patterns in words. Typically focusing on the development of lexicalized orthographic knowledge in the early elementary years, self-teaching suggests that the intense focus required to phonologically decode written words allows for the examination and learning of the orthographic information contained therein [33]. Oftentimes, a single encounter with a novel word or nonword is enough for children to encode orthographic detail [34]. In this way, the attention to specific letters and sounds required by phonological decoding may directly lead to increased orthographic knowledge, and orthographic understanding is specifically built on the foundation of phonological knowledge [35].

The development of orthographic knowledge also relies on phonological knowledge in other ways. Ricketts et al. [36] showed that early elementary children remember the orthography of consistent spelling-sound mappings (TROM

to rhyme with PROM) better than inconsistent spelling-sound mappings (TROM to rhyme with HOME), which suggests that learning specific orthographic representations relies, to a certain extent, on phonological transfer. This data suggests that some orthographic knowledge may be developed during the process of phonological recoding and be partially dependent on phonological knowledge.

By contrast, in some contexts, orthographic knowledge requires selectively overriding phonological knowledge. For example, Booth et al. [37] presented 9–15-year-old children with pairs of spoken words and asked them whether the rimes were orthographically the same. This allowed them to have pairs with both orthographic and phonological mismatches (“mint”/“pint”, “jazz”/“has”). They found that older children had more elaborate system for mapping the link between phonology and orthography, and children who performed the task better, specifically when there was a conflict between orthography and phonology, had more activation in the left inferior frontal gyrus, an area implicated in the hierarchical structuring of cognitive processes [38]. This suggests that, in some situations, judgments about orthography not only are about matching orthography, but also include a process of overcoming a conflict between orthography and phonology.

This selective override is also shown in studies of spelling development. When asked to create specific spelling combinations, children often use phonology to guide their spelling (e.g., [39–41]). For example, Hannam et al. [42] showed that children will often spell clusters like /sp/ (as in spin), with voiced stops (like sbin). In spoken language, the /p/ sound in the initial cluster often sounds more like a /b/ due to the early onset time of the voicing on the vowel and the lack of aspiration between the consonant and the vowel, suggesting that children may be producing the sound they hear more than paying attention to the orthographic spelling of the word. Bowman and Treiman [43] also found that a discrepancy between orthography and phonology can lead to difficulty in learning letter patterns. Children learn to spell words with a strong sound-spelling link quicker than words with an arbitrary spelling-sound link. Additionally, Stage and Wagner [44] examined young children's spelling of nonwords and found that, for kindergartners, a combination of phonological knowledge and working memory accounted for most of children's spelling choices.

In sum, early orthographic knowledge may develop partially through implicit computation of statistical patterns, but as children begin to actively decode words and require more specific orthographic knowledge, phonological knowledge must be integrated into that knowledge. In some contexts, phonological knowledge can scaffold orthographic knowledge, whereas, in others, phonological knowledge must be ignored in favor of orthographic knowledge. This proposes a model of phonological and orthographic development such that children's phonological and generalized orthographic knowledge develops in parallel for the first several years of life, and as children begin to receive direct instruction in reading during the preschool and early elementary years, these two systems must begin to be integrated. The current study attempts to directly test children's explicit and implicit orthographic knowledge as children are at this key point in

which they must begin integrating phonological and orthographic knowledge. In order to test this, we modelled a task after Treiman [39] and asked children to judge two nonwords on a screen on the basis of their orthographic legality in situations where they did or did not have to consider the phonology of the word. We track their gaze during this task to determine where they focus when they make their decision. Previous uses of eye-tracking technology have suggested that children's attention to stimuli may indicate an implicit understanding (e.g., [45, 46]). In addition to the general effect of focus on phonology on orthographic knowledge we expect different levels of response for different orthographic combinations. This study addresses the following questions:

- (1) Do Kindergarten children *explicitly* recognize the difference between legal and illegal orthographic combinations?
- (2) Does this recognition differ when children must consider phonology alongside orthography?
- (3) Do Kindergarten children *implicitly* recognize the difference between legal and illegal orthographic combinations?
- (4) Does this recognition differ when children must consider phonology alongside orthography?

2. Method

2.1. Participants. Forty-five Kindergarten students (mean age 5 years, 10 months; 39% females) were tested in schools. The ethnic diversity was representative of the school population, though less diverse than the overall population, with 5% of the sample being Hispanic and 2% of the sample being African American. All children were native English speakers.

2.2. Apparatus. Children were presented with a series of pseudowords and symbol strings on a computer monitor attached to a Tobii eye-tracking system by Tobii Technology AB (Tobii 1750). It is a remote eye-tracking system that has no contact with the reader. The system uses infrared cameras to automatically capture eye images from a reading distance. The system uses infrared video cameras to automatically acquire the pupil positions at a sampling rate of 50 Hz. The typical spatial accuracy, measured by repeated calibrations, is approximately 1 visual degree. Head movements typically resulted in a temporary accuracy error of approximately .2 visual degrees. In the case of particularly fast head movements (over 25 cm/s), there was a 300 ms recovery period to full-tracking ability.

2.3. Materials and Procedure. Participants were seated in an empty classroom, 63 cm away from the monitor during regular school hours. They then viewed a series of dots that appeared in an automatic 5-point calibration sequence (dots appeared in each corner as well as the center of the screen). Calibration accuracy was checked and repeated if necessary. After calibration and between each trial, a brief animation appeared to orient the child to the center of the screen.

At the beginning of the test, participants were told about a bear named Fiffi who only liked to eat words. They were then instructed to choose the "best" word for Fiffi, of the two nonwords presented on the screen. Children were instructed to place their fingers on the z or / keys for the entire study and to press down on the button to indicate the nonword on which side of the screen they thought was a "better" word. If at any time they have difficulty in performing the task they were encouraged and prompted accordingly.

Children then performed two lexical decision tasks. In the first task children are presented with a nonword on either side of the screen, one of which is orthographically legal and one of which is orthographically illegal (e.g., MOART/MOATR). Each word was 5 letters, written in capital letters in Times New Roman Font. Children were then asked which of the two nonwords was a "better" word. The second lexical decision task was similar to the first, but the nonwords were constructed in such a way as to be pronounced in the same way, even though one was illegal and one was legal (e.g., TESPERS/TESPR). Children were then asked which of the two nonwords was a "better" word for the spoken pronunciation of the word. Presentation of words on screen was counterbalanced left to right, and individual trials within each task were randomized and then presented in a set order.

Each lexical decision task included 4 trials of 3 types of illegal combinations:

- (1) Word initial stop/stop clusters (e.g., DTAM, BKON): these clusters are both phonologically and orthographically illegal. They can only be pronounced by turning the combination into a syllable (e.g., by adding a vowel sound in between the stops). These were categorized as subtle violations (see Section 3).
- (2) Word final stop/liquid clusters (e.g., MOATR, BAKL): these combinations are phonologically legal but orthographically illegal. These were also categorized as subtle violations (see Section 3).
- (3) Word initial consonant doublets (FFULP, LLORT): consonant doubles like "ff" are common at the end of words and fully pronounceable but illegal at the beginning of words. These were categorized as salient violations (see Section 3).

2.4. Coding. Eye movement data were scored with Tobii Studio software, which presents the videos superimposed with infants' eye fixations. Rectangular areas of interest were drawn to encompass the entire half of the screen each word was presented on. We then used Tobii Studio software to retrieve the total amount of fixation time to each AOI for the entire time the nonword remained on screen. Fixations were defined as any gaze coordinates lasting at least 60 ms and were identified using the Tobii Studio fixation filter. Adjacent gazes (i.e., gazes within a 0.5° radius, lasting less than 75 ms) were merged into a single fixation.

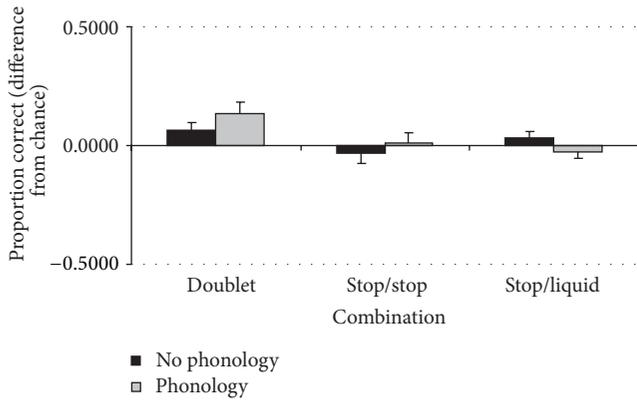


FIGURE 1: Children's explicit selection of "best word" by task and condition in proportion different from chance.

3. Results

3.1. Explicit Orthographic Knowledge

3.1.1. No-Phonology Task. Our first question addressed whether children would explicitly identify a legal orthographic combination over an illegal one. As shown in Figure 1, we found that children did not perform significantly differently from chance for either the word initial stop/stop, $t(44) = .44$, $p = .66$, or word final stop/liquid combinations $t(44) = 1.15$, $p = .258$. We did however find that children performed significantly above chance in the word initial doublet combinations $t(44) = 2.09$, $p = .04$. Taken together, these results suggest that Kindergarten children are able to explicitly identify some illegal orthographic combinations but not others (see Figure 1).

3.1.2. Phonology Task. Our next question examined whether these results would be consistent when children were asked to consider phonology in addition to orthography when identifying legal and illegal combinations. As in the no-phonology task, we found that children did not perform significantly differently from chance for either the word initial stop/stop combinations $t(43) = .04$, $p = .97$ or the word final stop/liquid combination $t(43) = .51$, $p = .61$, but they were able to identify the legal nonword when it involved word initial doublets $t(43) = 3.04$, $p = .004$. These results suggest that children's explicit knowledge is similar when making explicit orthographic judgments whether or not the phonology of the nonword is considered.

3.2. Implicit Orthographic Knowledge. To address our next questions we used eye-tracking to assess whether children implicitly identified illegal orthographic combinations and whether this may differ when phonology and orthography had to be considered at the same time. Based on children's explicit responses we collapsed the three combinations into two main groups. Word initial stop/stop combinations and word final stop/liquid combinations were categorized as *subtle illegal letter combinations*, whereas word initial doublets, because of children's explicit recognition, are categorized as *salient illegal letter combinations*.

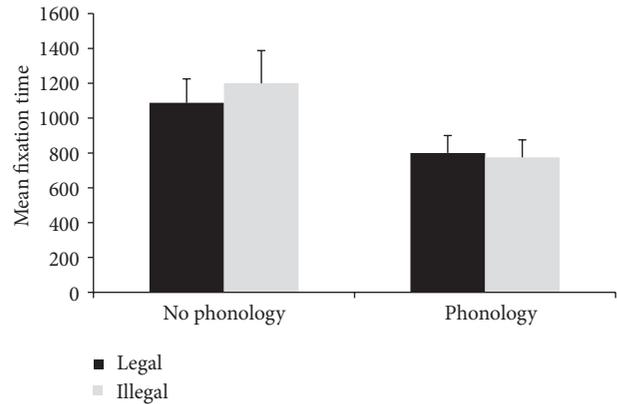


FIGURE 2: Fixation time at subtle nonwords by task and orthographic legality.

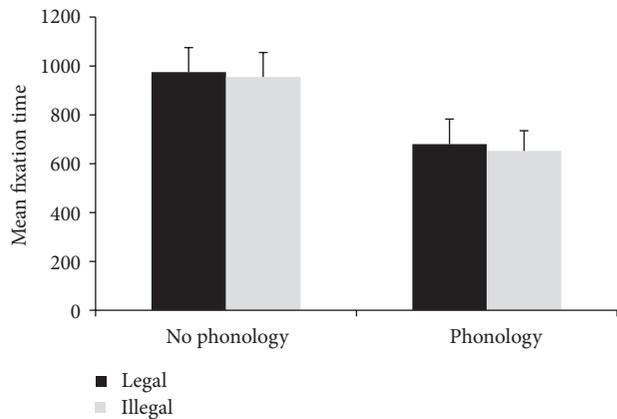


FIGURE 3: Fixation time at salient nonwords by task and orthographic legality.

3.2.1. Subtle Illegal Letter Combinations. In order to address whether children implicitly recognized subtle illegal letter combinations in the no-phonology task, we tested whether children looked longer at the illegal combination than the legal one. As shown in Figure 2, we found that children look longer at the illegal side of the screen, indicating an implicit recognition of illegality, $t(44) = 2.48$, $p = .017$.

When phonology was an additional consideration, however, we found no significant difference in looking time between legal and illegal nonword, $t(44) = .269$, $p = .789$. Taken together, these results suggest that it is only when they do not have to decode the nonwords that children show implicit awareness of subtle orthographic violations.

3.2.2. Salient Illegal Letter Combinations. We conducted a similar analysis to determine whether Kindergarten children showed implicit orthographic knowledge for salient illegal combinations. As shown in Figure 3, there was no significant difference between children's attention to the legal and illegal nonwords, in both the no-phonology, $t(44) = .146$, $p = .885$, and phonology, $t(44) = .378$, $p = .707$, conditions. These results suggest that when children have an explicit knowledge about the illegality of a letter combination, they do not spend more time inspecting the source of errors.

4. Discussion

This study examined children's explicit and implicit orthographic knowledge in situations where phonological knowledge was also being accessed. We found that, for salient violations of orthography, children have explicit awareness and can successfully choose the legal option over the illegal one, in either scenario. For subtler violations of orthographic rules, however, we find that children did not show explicit knowledge in either scenario but did show some implicit knowledge when phonology did not additionally have to be considered.

This research builds on a larger body of work that has shown implicit generalized orthographic knowledge in preschool and earlier (e.g., [17, 18]). The current study replicates these findings and extends them to show that early orthographic knowledge may be fragile. In particular, as children are learning to integrate their orthographic and phonological knowledge early in their reading development, focusing on the phonological component of written words may actually mask children's preexisting orthographic knowledge. This work supports an overall understanding of orthographic development in which generalized knowledge develops early and in parallel with phonological knowledge and then becomes integrated during the early years of independent reading in elementary school.

This research also reinforces the importance of exposure to written language in the early years. If the mechanism by which children attain early orthographic knowledge is statistical learning, as has been proposed by other studies (e.g., [21]), then considerable exposure to varied reading materials is the most likely way to build this type of orthographic knowledge in the early years. This would be consistent with decades of research in the educational realm that early exposure to print is essential for reading development (e.g., [47]).

There may be a number of potential explanations for this finding. First, adding the process of decoding to an orthographic compare-and-contrast task may be too demanding for children of this age. Decoding written words is dependent on the working memory capacity in the reader, as the assembly and breakdown of written words require active processing before it becomes automatic (e.g., [48, 49]), and Kindergarten students typically have lower working memory capacity than older children and adults (e.g., [50]). From this perspective, children may not be able to perform both tasks and therefore choose to prioritize phonological decoding over the orthographic comparison. This would suggest the importance of full integration of phonological and orthographical components of written language early in reading development, as young children seemingly do not have the cognitive capacity to consider both factors in tandem.

Furthermore, although these findings would seem to run in contrast to theories of orthographic development, like the self-teaching hypothesis [32], which argue that the phonological process of decoding leads to better attentiveness for letter patterns and increased orthographic knowledge, we caution against such an interpretation. The self-teaching work has focused mostly on specific orthographic representations

rather than the generalized knowledge about letter patterns tested here. It is possible that children learn specific representations through decoding, but they do not access previously existing orthographic knowledge when they are decoding, at least when they are very young. We may expect that if we asked children to remember the specific orthographic representations they saw in this study, they may have a stronger memory for the nonwords that were in the phonology inclusive task compared to the nonwords in the no-phonology task. This question was beyond the scope of the current study but remains an open question for future research.

An additional limitation of the current study is the lack of information available about the participants' backgrounds in reading, particularly in their overall reading ability, their phonemic awareness, their working memory skill, and their prior exposure to reading materials at home. Reading is a dynamic process influenced by many contextual factors [51] that were beyond the scope of this study but are important avenues for future research.

Overall this study provides strong evidence that a focus on sound-to-spelling correspondence in a judgment task can mask children's implicit orthographic knowledge. The reasons for this masking may have to do with children failing to access preexisting orthographic knowledge when they are focusing on the dual task of judgment and decoding. Nonetheless, this supports a theory in which generalized orthographic knowledge develops early but is masked by phonological knowledge early in reading development.

Competing Interests

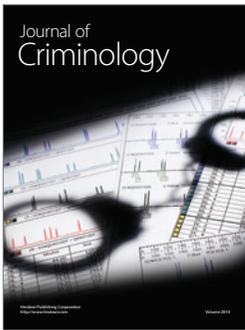
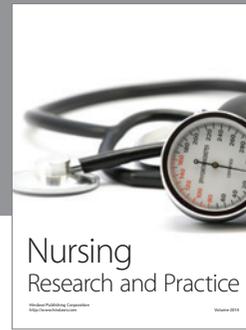
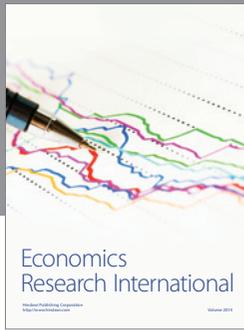
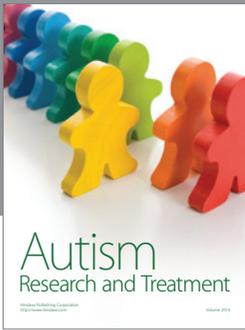
The author declares that they have no competing interests.

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