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Orthographic and semantic processing in young readers

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Abstract

This investigation examined orthographic and semantic processing during reading acquisition. Children in first through fourth grade were presented with a target word and two response alternatives, and were asked to identify the semantic match. Words were presented in four conditions: an exact match and unrelated foil (STONE – STONE – EARS), an exact match and an orthographic neighbor foil (STONE – STONE – STOVE), a synonym match and an unrelated foil (STONE – ROCK – EARS), and a synonym match and an orthographic neighbor foil (STONE – ROCK – STOVE). Accuracy and reaction time results suggest that orthographic and semantic processing follow a two-step acquisition pattern. First, the orthographic component of reading develops quickly, however, forming strong conceptual links from orthographic to semantic representations follows a protracted trajectory, which matures between the third and fourth grade. These results are consistent with research that suggests younger children rely on more concrete, perceptual systems and then transition to more flexible, abstract cognition.

Introduction

Learning to read is a difficult task, and arguably the most important in a child's elementary school years. Children must learn the alphabetic symbols and grapheme-phoneme correspondences to decode a word, and also must assign meaning to each deciphered word. While deciphering the orthographic symbols can be completed using lower-level visuo-perceptual systems, forming abstract, semantic representations from a written word requires higher-level, more conceptual processing. This suggests the involvement of multiple systems: those required for the perceptual visuo-spatial orthographic processing, and those required for more abstracted semantic processing of a word. The present experiment investigates the developmental profile of orthographic and semantic processing in young readers of English from the first to fourth grade.

Component models of reading propose that skilled reading requires the mastery and integration of distinct cognitive processes (e.g. Gough & Tunmer, 1986; Kendeou, van den Broek, White, & Lynch, 2009; Lonigan, Burgess, & Anthony, 2000; Whitehurst & Lonigan,

1998). Furthermore, many such models suggest that reading is the product of successful integration of multiple components comprised of different *levels* of cognitive processing. For example, skilled reading can be conceptualized as the product of successful integration of a lower-level perceptual component and a higher-level conceptual component. While nearly all descriptions of reading acquisition are in accord that a conceptual or semantic processing system is required to extract meaning from text, they differ as to the lower-level, more perceptual component. The vast majority of recent research focuses on how *phonological* processes interact with comprehension, and thus the importance of phonological awareness and decoding skills to successful reading acquisition has been well described (e.g. Anthony, Williams, McDonald, & Francis, 2007; Frost, Madsbjerg, Niersøe, Olofsson, & Sørensen, 2005; Goswami & Bryant, 1990; Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Muter, Hulme, Snowling, & Taylor, 1998; Muter, Hulme, Snowling, & Stevenson, 2004; Perfetti & Zhang, 1995; Wagner & Torgesen, 1987). Comparatively little is known, however, about the contribution of orthographic processing to reading comprehension during literacy acquisition and development (Nation, 2009).

In adult reading, the path from orthography to meaning has been, and continues to be, strongly debated (see Harm & Seidenberg, 2004). Both rule-based and connectionist models seek to explain how skilled readers use orthographic information to extract meaning from a written word. The Dual Coding Route theory (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) is a rule-based computational model of reading that provides a framework for understanding how phonological and orthographic processing interact with semantic processing. The Dual Coding Route proposes that there are two separate routes that can be used to comprehend a written word. The decision of which route to use is based on properties of the word itself. When the word is familiar and frequent, or contains irregular mappings from orthography to phonology, readers utilize a “direct route,” and access a semantic representation directly from an orthographic representation. When words are less familiar or more difficult, readers utilize a phonologically mediated route, in which they activate first the phonological information and subsequently access a semantic representation from the phonology (orthography to phonology to semantics). The phonological route can be compared to “sounding out” a word, as comprehension is thought to come from the sound, rather than directly from the written (orthographic) representation. Contrasting with this view, are connectionist or cascaded models (e.g. Plaut, McClelland, Seidenberg, & Patterson, 1996), which suggest that comprehension of a written word is accomplished by an increasing sensitivity to the statistical structure that exists between phonological, orthographic, and semantic representations. One such model, the Triangle Model, is introduced below.

The Triangle model (Plaut et al., 1996; Harm & Seidenberg, 2004) is a connectionist model, which suggests that there is both a pathway from orthography to phonology *and* a pathway from semantics back to orthography and phonology. It is assumed that these pathways operate in tandem, and that comprehension is achieved via graded representations of the pathways working simultaneously. The weights attached to each of the pathways, however, may shift as a function of the word context. As such, the Triangle Model indicates that semantics is involved in the orthographic decoding of *all* items, not only the decoding of

high frequency words, or words with inconsistent orthographic to phonological mappings. While these two approaches to understanding reading comprehension have been well studied in adult reading (for a review of orthographic processing in adults, see Grainger (2008)), we know very little about the processes involved in creating efficient form to meaning mappings during reading acquisition (Castles & Nation, 2008; Nation, 2009).

One possible explanation for the scarcity of research into orthographic processing during reading development is that orthographic and phonological processes are closely related, making it difficult to study the influence of orthographic and phonological processes independently (Cunningham, Perry, & Stanovich, 2001). This is especially true during reading acquisition, when children learn to link a visual code with a phonological representation. According to Jorm and Share (1983), successful phonological decoding of words is coupled with the full orthographic representation of the word, resulting in “positive learning trials,” in which each successful decoding of a new word provides an opportunity to acquire word-specific orthographic information about that word. In this view, phonological decoding is constantly reinforcing the orthographic representation, leading to a merged phonological and orthographic representation of each known word. This compound phonological-orthographic representation likely contributes to efficient word recognition (Ehri & Wilce, 1980; Perfetti, 1992), and makes it difficult to disentangle the independent contributions of orthographic and phonological components to the development of skilled reading.

Although it is clear that orthographic and phonological processes are closely related during the reading acquisition time window, orthographic processes are not entirely dependent on phonological processes (Burt, 2006; Reitsma, 1983; Stanovich & West, 1989), and orthographic and phonological processes have been shown to exert unequal influence on the reading process (Bekebrede, Leij, Plakas, Share, & Morfidi, 2010). Indeed recent research suggests that differences in orthographic processing account for unique variance in reading proficiency, which cannot be explained by differences in phonological processing alone (e.g. Badian, 2001; Castles, Holmes, Neath, & Kinoshita, 2003; Treiman & Cassar, 1997). Such research suggests that understanding the processes involved in efficient orthographic processing may contribute to a better understanding of reading development as a whole (Aghababian & Nazir, 2000). In one such experiment, Pratarelli Perry, and Galloway (1994) investigated the visual encoding of words in children compared to adults in order to determine whether or not children were less skilled in automatic lexical access. Nine and ten-year-old children made lexical decisions on content and function words following a brief (50ms) prime word that was either graphemically related (e.g. dog - DOG) or unrelated (dog - BRICK). They found that while adults were faster in all conditions, the facilitation priming effect was the same in adults and children, suggesting that graphemic visual encoding was similar between groups. While these results shed light on the visual encoding of graphemic information, they do not necessarily extend to orthographic similarity. Furthermore, the children in the young reader group were already nine and ten years old, and arguably not beginning readers.

A study by Nation and Cocksey (2009) extends these results to investigate *orthographic* encoding in a group of younger children. In this experiment, young children were asked to

make categorical judgments about visually presented words, some of which contained an embedded word that was related to the category (e.g. *hip* is embedded in *ship* and is a category member of *body parts*). Children in this investigation were slower to reject *ship* as a member of the category *body part* in comparison to the category *animal* because *ship* contains an embedded category member. Furthermore, it was discovered that this inhibition effect remained even when the pronunciation of the embedded word differed from the carrier word (e.g. *crow* does not share pronunciation with its carrier *crown*, though orthographically it is an embedded category member of *animal*). These results strongly suggest that even children as young as seven years of age activate meaning directly from the orthography of the word.

Further evidence for the early role orthographic processing plays in reading acquisition comes from a study by Zecker (1991). In this study, children ages seven to eleven participated in an auditory rhyme detection task. Within the rhyme trials, half of the targets were orthographically similar to the cue (e.g. BUM – GUM) and half were orthographically dissimilar (e.g. THUMB – GUM). Results demonstrated that typically developing children, as young as seven years of age, showed a facilitation effect for detecting the auditory rhyme when the orthography was similar, and that the orthographic facilitation became more robust in older age-groups. These results also suggest that children automatically activate the orthographic representation of an auditory word quite early, but that the orthographic representation continues to become stronger with development.

There also exists some evidence that purely orthographic representations may precede phonological representations in the early stages of reading acquisition (Rayner, 1988). Such evidence has its foundations in the finding that orthographic processing is more strongly correlated with earlier-acquired, visuo-perceptual performance than later-acquired, unobservable, abstract processing (such as phonological or semantic processing) (Boets, Wouters, van Wieringen, De Smedt, & Ghesquière, 2008). If the cognitive skills that support orthographic processing develop earlier than those which support semantic processing, it is reasonable to expect that the acquisition and development of orthographic and semantic components of reading will follow different developmental trajectories: Initially, orthographic processing (supported by lower-level visuo-spatial skills) will be more robust, and later in reading acquisition, both orthographic and semantic components will become comparably proficient. This integration of reading components results in rapid and efficient linking between orthography and meaning, which is one of the hallmarks of skilled reading (Castles & Nation, 2008).

Many Stage Models of Reading describe the process of reading acquisition as just such a transition: from a rigid reliance on concrete, observable aspects of a visual word, to more flexible, abstract representations (Marsh, Friedman, Welch, & Desberg, 1981; Mason, 1980; and see Rayner & Pollatsek, 1989 for a review). In early stages of reading development, for example, features of the orthography tend to be more salient to young readers than what the symbols represent (i.e. a phonological or semantic representation). In these early stages, children may use visual aspects of the word to remember its meaning (e.g. *look* has two eyes) (Gough, Juel, & Griffith, 1992), and rely more heavily on the boundaries of the word (first and last letter) than the medial portions. Readers in these early stages also may confuse

words that have the same initial and final letter, even when the words differ in the middle (e.g. *spoon* and *skin*) (Ehri, 2005). From this standpoint, reading acquisition can be viewed as a period when children learn to integrate the concrete observable components with more abstract components, resulting in efficient form to meaning mappings to support reading.

Additional evidence that beginning readers are more reliant on perceptual aspects comes from a study by Rayner (1988) in which children of different reading levels were asked to decide which response alternative was most like a target (e.g. *cabin*). They found that pre- and beginning readers responded most often on the basis of word shape and initial letter (e.g. responding that *cadin* is more similar to *cabin* than *kabin*), indicating that for beginning readers most like was synonymous with the perceptual interpretation *looks most like*, rather than a more abstract interpretation such as *sounds most like*. Following this task, children were asked which response alternative *sounded most like* the target, thereby drawing children's attention to the more abstract, phonological representation. Results demonstrated that the youngest readers continued to identify the response alternative that *looked* most like the target. Intermediate readers (eight-year-old children with three years of reading experience) initially tended to interpret *most like* to mean *looks most like*, but when asked to identify the word that *sounded most like* the target word, eight year olds changed their answer to the closest homophone. This suggests that while the concrete orthographic cues were still the most salient for eight-year-olds, they had the cognitive flexibility to recognize a different, more abstract dimension when cued to do so. Ten-year-olds (with about five years of reading experience), tended to choose the response alternative that sounded *most like* the target without direct instructions, suggesting that by ten years of age, *most like* is synonymous with a more abstract dimension *sounds most like*. Rayner's (1988) investigation provides evidence that for early readers, the observable features of the orthography are the most salient aspect of a written word until about ten years of age, when the non-observable, phonological representation becomes the most salient.

Some evidence suggests that establishing good orthographic processing skills early in reading development is critical for later automatic word recognition and reading comprehension (Ehri, 2005). However, while measures of orthographic processing in preschool were predictive of reading comprehension in seventh grade, they were not predictive of reading performance in the first and third grades (Badian, 2001). It thus appears that establishing a strong foundation in orthographic processing is critical to later reading comprehension, but that children do not rely heavily on orthographic processing in the middle elementary school years, likely due to the development of phonological processing. A comprehensive model of reading development would therefore include the development and interaction of orthographic, phonological, and semantic processes. This is outside the scope of this paper, however, which concentrates on orthographic and semantic processes, and the connections that are formed between these two components during reading acquisition.

Some models propose a child's increase in language proficiency and vocabulary is the primary impetus for integrating orthography and semantic processes. The *lexical tuning hypothesis* (Castles, Davis, Cavalot, & Forster, 2007; Castles, Davis, & Letcher, 1999), for example, suggests that an increase in vocabulary acts as a catalyst in forming links between

orthographic and semantic representations. Specifically, the lexical tuning hypothesis posits that orthographic processing is continually “tuned” as children acquire larger vocabularies. Early in reading acquisition, the orthographic processing system is coarsely tuned, and thus accepts similar (but not identical) inputs as candidates for a target word. Young readers, for example, would be likely to accept an orthographic neighbor, such as *bib* as identical to the word *bid*. As children acquire more words and become more experienced readers, however, this loose orthographic criterion becomes increasingly stringent, and children demonstrate more finely tuned orthographic processing. Thus, the lexical tuning hypothesis emphasizes the interconnected nature of orthographic and semantic processing during the reading acquisition time window, and highlights the necessity for further investigation of the developmental profile of both components.

Castles and colleagues (2007) found evidence for the lexical tuning hypothesis using a masked priming longitudinal design. In this investigation, adults and children (at grade three and then again at grade five) made lexical decisions about words following a masked prime that was either a substitution of the target word (e.g. rlay: PLAY), a transposition of the target word (e.g. lpay: PLAY), or orthographically unrelated to the target word (e.g. meit: PLAY). This investigation found that while adults showed little or no facilitation from non-word primes that differed from the target by one letter, the third grade children demonstrated large facilitation effects. At fifth grade, the facilitation effects were diminished. The authors interpret these results to suggest that word recognition processes change from broadly to finely tuned. Since children demonstrated facilitation from a non-word prime that differed by one letter from a target (and adults did not) in the younger grades, this suggests that the orthographic word recognition mechanism accepted the orthographic neighbor as the target, thus priming the lexical decision. In adulthood, the non-word orthographic neighbor did not prime the target word and resulted in little or no facilitation of the meaning, presumably because more real word orthographic neighbors exist in the lexicon (e.g. bid, bib, bit, big, bin).

Currently, there are few studies that address the development of the orthographic and semantic processing systems in relation to one another in the same task within the reading acquisition window (studies that have addressed this question include Castles et al., 2007; Nation & Cocksey, 2009; Pratarelli et al., 1994; Zecker, 1991, summarized above). It is not clear, therefore, whether orthographic and semantic processes mature concurrently during reading acquisition, or whether these processes follow different developmental trajectories, leading to strengths and weaknesses in orthographic and semantic processing at different stages during reading acquisition.

The current experiment differs from other investigations of how and when orthography influences reading comprehension in that it uses a synonym detection task to probe comprehension of meaning (rather than lexical decision (Castles et al., 2007), category judgment (Nation & Cocksey, 2009), or rhyme detection (Zecker, 1991)), and directly pits similar semantics (synonyms) with similar orthographic forms (orthographic neighbors) within a single experiment, and within subjects. Using this novel experimental design, children's accuracy and reaction times to identify semantically and orthographically similar pairs are compared. This experiment allows a glimpse into the development of the

orthographic and semantic processing systems, and provides insight into how and when these two systems function together to support reading. This investigation explores the possibility that there exists a transition from an orthography first strategy (such as would be expected by the phonologically mediated pathway of the Dual Coding Route (Coltheart et al., 2001) and linear models of reading (e.g. Morton, 1969)), to a more semantically influenced comprehension strategy, where the meaning of the word influences orthographic and phonological processes (as would be expected by more cascaded/connectionist model such as the Triangle Model) (Harm & Seidenberg, 2004; Plaut et al., 1996).

Children in the first through fourth grade were asked to make semantic similarity judgments regarding a target word (e.g. STONE) when there was either an orthographic match with an unrelated foil (e.g. STONE and EARS), an orthographic match with an orthographic neighbor as a foil (e.g. STONE and STOVE), a semantic match with an unrelated foil (e.g. ROCK and EARS), or a semantic match with an orthographic neighbor as a foil (e.g. ROCK and STOVE). It was predicted that accuracy and reaction time results would support the hypothesis that the orthographic code is established quite early, but due to weaker associative links joining perceptual, orthographic representations with conceptual, semantic representations, the younger children in the reading acquisition time window will be less efficient to map this orthographic representation onto a semantic representation. This hypothesis would be supported if younger children demonstrate faster, more accurate processing of conditions requiring orthographic processing (Orthographic condition); slower, though accurate performance on conditions probing semantic processing (Semantic condition); and less accurate, but rapid performance on the condition directly comparing orthographic and semantic processing (Orthographic-semantic condition). Older readers, by contrast, are expected to demonstrate similar reaction time and accuracy to Orthographic and Semantic conditions and higher accuracy on the Orthographic-semantic condition. Such a pattern of results would suggest that children transition from more perceptually based (orthographic) to more abstract (semantic) representations of written words during reading acquisition.

Experiment 1

Methods

Participants—Eighty typically developing children from San Diego public schools participated in Experiment 1: Twenty first graders (12 female, 8 male; M age = 6.96 years; SD = .29), 20 second graders (11 female, 9 male; M age = 8.10 years; SD = .28), 20 third graders (11 female, 9 male; M age = 8.99 years; SD = .39), and 20 fourth graders (15 female, 5 male; M age = 9.98 years; SD = .44). All children were participating in English curriculum at school and demonstrated conversational competence in English (via teacher report, as well as an informal conversational assessment administered by the experimenter). Two first grade participants were excluded from analyses based on an inability to read single words in English.

Materials—Twenty-six sets of word triads were designed to be appropriate for young elementary school children (see Appendix A). Each triad contained a “target” word, a “match” word (the correct choice for that particular trial), and a “foil” word (the incorrect

choice for that particular trial). Word-pairs designated as “match” and “foil” were normed on 100 undergraduate students from San Diego State University, who rated the semantic similarity of word-pairs on a Likert scale (1 = extremely different meanings and 7 = extremely similar meanings). Only those pairs that were rated as an average of 5.5 and above ($M = 6.06$; $SD = .33$) were used as a “match,” and only those that were rated as an average of 1.5 and below ($M = 1.35$; $SD = .83$) were used as a “foil.”

Target, match, and foil stimuli were matched in word frequency based on the Hyperspace Analogue to Language (HAL) corpus norms (Lund & Burgess, 1996), which consists of approximately 131 million words gathered across 3,000 Usenet newsgroups during February 1995 (Balota et al., 2007). Since participants chose between the match and the foil in each trial, it was important that the match and foil not differ in terms of word frequency, as that would bias participants toward one response alternative over another. Paired t -tests reveal that there were no significant differences between the frequency of the match and foil, according to the HAL frequency corpus $t(25) = .326$, $p > .1$. Match, Foil, and Target words were all between 3 and 6 letters, and match and foil words were not significantly different in length (number of letters) $t(25) = 1.9$, $p > .05$.

All three words (“target,” “match,” and “foil”) were presented simultaneously on a touch screen monitor (Dell 15-inch Touch-screen Flat Panel). Words were presented in all capital letters (size 40 Arial font) and for salience were presented within white rectangles on a black screen. The “target” word was centered at the top of the screen, and the “match” and “foil” were presented beneath the “target” at the left and right sides of the screen (see Figure 1 for a schematic of study design).

The side of the “match” on the visual display was pseudorandomized such that each participant saw an equal number of “match” and “foil” words on the right and left sides of the screen, but the location of the “match” was not predictable. Each child responded to 26 trials that met norming criteria (participant average rating of 5.5 and above for synonyms and average of below 1.5 and below for foils). Four lists were created containing 6 trials of two conditions and 7 trials of the remaining two conditions, which then were counterbalanced across participants so that an equal number of each condition was presented across participants. Thus, each participant saw each stimulus word in only one of the four conditions, and participants did not see any words repeated more than once to avoid repetition effects (for examples of stimuli and counterbalancing, see Table 1 and Appendix A).

Procedure—Participants were tested individually in a quiet room at their school. In order to ensure that all participants within a grade cohort were at the same point in their academic curricula, all testing took place in the months of April and May (within the final months of the academic year). Children were seated in front of a touch screen monitor and were instructed to use one finger to touch the word that “means the same thing” as the “target” word. Children were informed that for this experiment, *means the same thing* could be either the exact same word (e.g. BOAT-BOAT), or a synonym of that word (e.g. BOAT-SHIP). All participants completed a 10-trial practice block with accuracy feedback to ensure understanding of the procedure. Participants were not given feedback during the

experimental trials. Although accuracy was emphasized, children were asked to answer as quickly as possible. The stimuli remained on the screen until the child made his or her response by touching one of the response words. In order to decrease variability associated with fatigue and distractions, the experiment was self-paced. After each response, an interim screen appeared, instructing the child to touch the screen when he/she was ready to proceed with the next trial. During the practice block, children were taught to rest between trials (when the picture was on the screen) rather than during experimental trials (when the words were on the screen).

Experimental Conditions—Four conditions were presented: Baseline, Orthographic, Semantic, and Orthographic-semantic (Refer to Appendix A for full list of stimuli).

In the Baseline condition, the “match” was the same word as the “target” (orthographically identical), and the “foil” was unrelated both orthographically and semantically (e.g. LADY (target); LADY (match); WATER (foil)). This condition required participants to execute a perceptual matching task, and it measured the time the child took to match the “word-shape” (see Rayner, 1988) and make a physical response (touching a word on the screen). Crucially, in the Baseline condition, no semantic processing or finely tuned orthographic processing was required.

In the Orthographic condition, the “match” was also orthographically identical to the “target” but in this condition the “foil” was an orthographic neighbor of the “target;” it differed from the target word by only one letter (e.g. LADY (target); LADY (match); LAZY (foil)). Thus, this condition required the child to execute a very finely tuned orthographic discrimination task (instead of simply matching word-shape) to determine that the “target” and the “foil” were indeed different words. However, this Orthographic condition did not demand semantic processing.

In the Semantic condition, the “match” was a synonym of the “target,” and the “foil” was unrelated both semantically and orthographically (e.g. LADY (target); WOMAN (match); WATER (foil)). In this condition the participant was required to process the meaning of the word, but was not presented with a perceptual, orthographic foil.

In the Orthographic-semantic condition, the “match” was a synonym of the “target” and the “foil” was an orthographic neighbor of the “target” (e.g. LADY (target); WOMAN (match); LAZY (foil)). In this condition, semantic processing and orthographic processing were in direct competition because it required participants both to perform a perceptual orthographic discrimination task to determine that the “target” and the “foil” were different words, and to access their semantic lexicon in order to determine that the “match” was semantically (though not perceptually) related to the “target.”

Results

Data were analyzed using two 4 (Grade) $\times$ 4 (Condition) repeated measures ANOVAs, one with the proportion correct as the dependent variable and one using mean (untrimmed) reaction times normalized by accuracy (Efficiency scores) as the dependent variable. Ulrich and Miller (1994) argue that trimming extreme reaction times introduces considerable bias,

as truncating data can eliminate data points that may be extreme, but are not spurious. In the present experiment, the data were collected by the first author, who ensured that long reaction times were indeed due to longer processing times, rather than equipment failure, interruption, or other spurious event unrelated to the experimental task. As such, similar to other investigations of reading development (e.g. Nation & Snowling, 1998, 1999), as well as recent developmental cognitive neuroscience experiments (e.g. Clarke, Taylor, & Tyler, 2011), the present investigation does not remove outliers. The variability introduced by including possible outliers (especially in the younger grades) will be reflected upon within the discussion section.

Accuracy Results—Accuracy results yielded a significant main effect of Grade, $F(3,17) = 9.64, p < .01, \eta_p^2 = 0.63$ and a significant main effect of Condition $F(3,17) = 58.00, p < .001, \eta_p^2 = 0.91$. There was also a marginally significant Grade $\times$ Condition interaction $F(9,11) = 2.82, p = .054, \eta_p^2 = 0.70$ (See Table 2). Paired samples t -tests of accuracy reveal that in the first grade children responded to the Baseline condition with significantly higher accuracy than the Orthographic condition $t(19) = 2.43, p < .05$ and responded to the Semantic condition with significantly higher accuracy than the Orthographic-semantic condition $t(19) = 5.77, p < .001$. Although there was no observed difference in accuracy between the Orthographic and Semantic conditions in the first grade ($t(19) = 1.49, p > .05$), large differences between these conditions existed in reaction time results, which are reported below (See Table 3). Paired samples t -tests of accuracy in the second grade participants demonstrated a similar pattern: Children responded to the Baseline condition significantly more accurately than the Orthographic condition $t(19) = 2.09, p = .05$ and to the Semantic condition significantly more accurately than the Orthographic-semantic condition $t(19) = 4.08, p < .01$. There was no difference in accuracy between the Orthographic and Semantic conditions in the second grade $t(19) = .23, p > .05$. In the third grade, children responded with significantly higher accuracy to the Semantic compared to the Orthographic-semantic condition $t(19) = 3.40, p < .005$, but there was no observed difference in accuracy between the Baseline and Orthographic conditions $t(19) = 1.03, p > .1$ or between the Orthographic and Semantic conditions in the third grade $t(19) = .34, p > .1$. In the fourth grade, there was a marginally significant difference between Semantic and Orthographic-semantic conditions (such that children responded to the Semantic condition more accurately than the Orthographic-semantic condition), $t(19) = 1.93, p = .069$, but no differences were observed between Baseline and Orthographic $t(19) = 1.00, p > .1$, or Orthographic and Semantic conditions $t(10) = 1.28, p > .1$. While these results describe the response outcome (correct or incorrect), they do not provide a representation of processing speed or efficiency, which are reported below.

Reaction Time Results—Because children in the first grade performed with such low accuracy on the Orthographic-semantic condition, reporting statistics on correct trials only did not accurately reflect the sample. Additionally, due to a speed-accuracy trade off in the Orthographic-semantic condition, reporting statistics on reaction time results alone also did not accurately depict the data. To account for this speed-accuracy trade off, analyses were performed on the mean reaction time for each participant for each condition divided by the mean accuracy for each participant in each condition. These Efficiency Score analyses

(Christie & Klein, 1995; Townsend & Ashby, 1983) yielded a significant main effect of Grade $F(3,17) = 8.38, p < .01, \eta_p^2 = 0.60$, and a significant main effect of Condition $F(3,17) = 15.93, p < .001, \eta_p^2 = 0.74$. A significant Grade $\times$ Condition interaction $F(9,11) = 6.98, p < .01, \eta_p^2 = 0.85$ was also observed (see Figure 2).

Between Grade, within Condition Follow-up Paired Comparisons of Efficiency

—Follow-up paired samples t -tests of the conditions across grade reveal that in the Baseline condition, children in the second grade performed with significantly more efficiency than those in the first grade $t(19) = 2.64, p < .05$, children in the third grade performed with marginally more efficiency than children in the second grade, $t(19) = 1.95, p = .06$, and no difference in Baseline processing efficiency existed between the third and fourth grade $t(19) = 1.12, p > .1$. In the Orthographic condition there was a marginal difference between the first and second grade (such that the second graders responded more efficiently) $t(19) = 1.81, p = .08$; a significant difference between the second and third grade (such that the third graders responded more efficiently) $t(19) = 1.39, p < .05$, and no difference between the third and fourth grade $t(19) = .64, p > .1$. In the Semantic condition, children in the second grade performed with more efficiency than those in the first grade ($t(19) = 2.95, p < .005$) and children in the third grade performed more efficiently than those in the second grade ($t(19) = 2.34, p < .05$). No significant difference was observed in Semantic efficiency between the third and fourth grade $t(19) = 1.20, p > .1$. In the Orthographic-semantic condition, there was no significant difference between the first and second grade $t(19) = 1.51, p > .1$, a marginal difference between the second and third grade (such that the third graders responded more efficiently), and no significant difference between the third and fourth grade $t(19) = 1.89, p = .075; t(19) = 1.43, p > .1$ (respectively).

Within Grade, Between Condition Follow-up Paired Comparisons of Efficiency

—Follow-up paired samples t -tests within grade and across condition reveal that in the first grade responses to the Baseline condition were significantly more efficient than the Orthographic condition, responses to the Orthographic condition were significantly more efficient than the Semantic condition, and there was no significant difference in response efficiency between the Semantic and Orthographic-semantic conditions $t(19) = 2.17, p < .05; t(19) = 3.37, p < .005; t(19) = 11.28, p > .1$ respectively. The same pattern was true for the second grade: Responses to the Baseline condition were significantly more efficient than to the Orthographic condition, $t(19) = 3.31, p < .005$, responses to the Orthographic condition were significantly more efficient than to the Semantic condition $t(19) = 2.28, p < .05$, and there were no observed differences between the Semantic and Orthographic-semantic conditions in the second grade $t(19) = 1.49, p > .1$. In the third grade, responses to the Baseline condition were more efficient than to the Orthographic condition $t(19) = 2.37, p = .05$ and responses to the Orthographic condition were more efficient than to the Semantic condition (with marginal significance) $t(19) = 1.81, p = .08$. No differences were observed between Semantic and Orthographic-semantic processing efficiency in the third grade $t(19) = 1.62, p > .1$. In the fourth grade no differences were observed between the Baseline and Orthographic conditions $t(19) = 1.53, p > .1$ or between the Orthographic and Semantic conditions $t(19) = .42, p > .5$, but a significant difference was observed between the Semantic and Orthographic-semantic conditions, such that fourth graders responded to the

Semantic condition with more efficiency than the Orthographic-semantic condition $t(19) = 2.46, p < .05$.

Results from Orthographic and Semantic Conditions—In order to control for the possibility that younger children were just slower to respond overall (i.e. differences are not due to the orthographic and semantic experimental manipulation), the mean reaction time for the Baseline condition was subtracted from the mean reaction time for the Orthographic and Semantic conditions for correct trials only. This subtraction provided a measure of orthographic and semantic processes isolated from other, more general, task demands. These differences (Orthographic – Baseline and Semantic – Baseline) were then compared within grades to achieve a measure of the fluency of orthographic and semantic processing between grades. Even after controlling for general task demands (subtracting the Baseline condition from the Orthographic and Semantic conditions), the pattern of orthographic and semantic processing results for children in the first through fourth grades remained the same: Paired t -tests revealed orthographic processing speed to be significantly faster than semantic processing speed (Orthographic – Baseline compared to Semantic – Baseline respectively) in the first grade $t(19) = 3.20, p < .005$; second grade, $t(19) = 2.22, p < .05$; marginally in the third grade $t(19) = 2.01, p = .059$; and in the fourth grade there was no significant difference between orthographic and semantic processing speed $t(19) = .10, p > .05$ (See Figure 3).

Discussion

Accuracy analyses revealed that older children were more accurate than younger children overall, but also that younger children were relatively less accurate than older children to identify the semantic match (e.g. SHIP for BOAT), when in the presence of an orthographic foil (e.g. BOOT). In this condition (Orthographic-semantic), the children in the first grade chose the orthographic foil more often than the correct synonym match (and more often than would be predicted by chance), suggesting that they accepted the orthographic neighbor as the target word. One question that may arise from such a result is whether these young children knew the meaning of the synonym match, or whether they were guessing between an unknown word, and a word that was perceptually similar. Importantly, the Semantic condition acted as a control for the Orthographic-semantic condition. In the Semantic condition, children (between subjects) saw the same target and match word, but the foil was unrelated both orthographically and semantically to the target word. Therefore, if children did not know the synonym match, they would have performed at chance on the Semantic condition. This was not the case. While children in the first grade performed with only 43% accuracy on the Orthographic-semantic condition, their performance on the Semantic condition was significantly higher (79% correct), suggesting that it was indeed the presence of the orthographic neighbor which caused young readers to err, rather than the possibility that the children did not know the meaning of the synonym match in the Orthographic-semantic condition.

These results support lexical tuning hypothesis (Castles et al., 2007), which suggests that younger children have more “coarsely-tuned” orthographic processing, and thus were more likely to accept an orthographic neighbor as a target word. This is apparent from the accuracy and efficiency results of the Baseline relative to Orthographic condition in the

younger compared to older participants. Results demonstrate that responses to the Baseline condition (no orthographic foil) were more *accurate* relative to the Orthographic condition (orthographic neighbor foil) in the first and second grade, but not the third and fourth grade. Responses were also more *efficient* in the Baseline condition relative to the Orthographic condition in the first, second, and third grade but not in the fourth grade. Thus, both accuracy and efficiency results indicate that the younger groups accepted the orthographic neighbor as the target more often than an orthographically unrelated foil, suggesting a gradual tuning of orthographic processing. However, according to the lexical tuning hypothesis, it is vocabulary growth that drives the fine-tuning of the orthographic processing system. It is an assumption of the current experiment that the children in the older grades did indeed have larger vocabularies, as no specific standardized vocabulary measures were taken, and vocabulary size was therefore not specifically correlated with performance on the experimental conditions. Because all children in the study were typically developing, participated in age-appropriate school curricula, and had no history of learning or developmental delay, however, it seems reasonable to assume that vocabulary size and age were closely correlated in this sample of elementary school children, as is the case for typically developing children in general.

Efficiency scores revealed that younger children performed well on the conditions requiring orthographic processing (Baseline and Orthographic), but less efficiently on conditions that required semantic processing. Importantly, there was a qualitative difference between young participants' performance on the Semantic condition (synonym match without an orthographically related foil) and the Orthographic-semantic condition (synonym match and orthographic neighbor foil). First graders, on average, responded slowly with high accuracy to the Semantic condition, but quickly and with low accuracy to the Orthographic-semantic condition. These two conditions both require the selection of a synonym match, and differ only in terms of the foil word, specifically the presence or absence of an orthographic neighbor. This result suggests that while children in the youngest age group could indeed identify the synonym match correctly, these children relied too heavily on a coarsely-tuned orthographic processing system, which prompted them to incorrectly respond that the orthographic neighbor was the target word.

Children in the first grade were highly variable in their reaction time to identify the target. Since the first author collected all the data individually, however, it can be verified that even the longest latencies were due to processing time. Because it appears that the variability in this youngest age group is an important hallmark of reading development, we have chosen not to remove data points that may be considered outliers (Ulrich & Miller, 1994). However, we note that only one data point falls more than three standard deviations above the mean (a first grader's response to the Orthographic-semantic condition), and no reaction times (in any of the grades) were less than one second, a time-window which may be considered to be an uninterpretable fast response time for the task at hand. Additionally, even the children who took a very long time to process the written stimuli, demonstrated a greater than chance performance on the Semantic condition. We believe that the high variability of the first grade readers in the conditions requiring semantic processing is attributable to the transition from an orthographically-based to semantically-based reading strategy. While some of the

first graders have begun to activate some meaning directly from the text, others continue to sound out the word, resulting in much longer reaction time, less efficient reading, and consequently increased variability within this age-group. The results from the youngest group of participants can be explained within linear models of reading such as the phonologically mediated pathway of the Dual Route, which suggest that the pathway from decoding to comprehension occurs in a more serial manner (e.g. Morton, 1969; and see Lupker, 2008 for a review of linear and cascaded models). Results from the older participants, however, suggest a more cascaded or connectionist route from orthographic to semantic representations, such as the triangle model. Results from older participants are discussed below.

In contrast to the youngest group of readers, children in the second, third, and fourth grade demonstrated the slowest reaction times (and least efficient processing) to the Orthographic-semantic condition. In these older grades, when the semantic information from the orthographic neighbor (foil) was in competition with the semantic information from the synonym match, children showed slower reaction times, indicating that some semantic processing occurred *before* completion of the orthographic processing. This interference effect suggests that by second grade, the route from orthography to meaning was more cascaded (e.g. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Forster & Hector, 2002).

One outstanding question, however, is whether the orthographic processing investigated in Experiment 1 is truly a learned component specific to reading, or whether children were simply matching symbols in the Baseline and Orthographic conditions. Experiment 2 is thus a control experiment designed to address the possibility that children were using a symbol search strategy to complete to the Orthographic and Baseline conditions, rather than utilizing learned orthographic processes specific to reading.

Experiment 2

Introduction

Experiment 2 is an experimental control condition, which tests the hypothesis: Is the early-established orthographic representation evidenced in Experiment 1 specific to reading in a learned orthography, or would children demonstrate the same pattern of results when matching any complex visual stimuli? To address this possible confound, the same stimuli from the Baseline and Orthographic conditions in Experiment 1 were presented in a false font (unfamiliar letter-like visual stimuli that do not contain any meaning) in Experiment 2 (for examples see Table 4). If the efficient orthographic processing observed in Experiment 1 did *not* index the acquisition of a component of reading, but rather reflected a symbol matching strategy, then matching any set of word-like complex visual stimuli should evoke a similar pattern of accuracy and reaction time results to Experiment 1 in the conditions that do not require semantic processing. If, on the other hand, the results from Experiment 1 *did* reflect a component specific to reading acquisition (namely orthographic processing), we would expect orthographic processing in Experiment 2 (false font) to be processed less efficiently than that observed in Experiment 1 (real words).

Methods

Participants—Thirty-two typically developing children from San Diego public schools participated in Experiment 2: Eight first graders (4 female, 4 male; M age = 7.06 years; SD = .37), 8 second graders (5 female, 3 male; M age = 7.97 years; SD = .31), 8 third graders (3 female, 5 male; M age = 8.77 years; SD = .56), and 8 fourth graders (4 female, 4 male; M age = 9.87 years; SD = .27).

Procedure and Materials—The same experimental paradigm from Experiment 1 was employed in Experiment 2, with the exception that all stimuli were presented in a false font (Microsoft Word Wingdings 3). Wingdings 3 is a false font based on the English alphabet (one symbol stands for one letter), but the “letters” do not resemble letters from the Roman alphabet. Because each false font symbol represents one English letter, the same words from Experiment 1 were presented, but in this non-meaningful font. Thus, Word length and proportion of similarity between the Baseline and Orthographic conditions remained the same across Experiments 1 and 2. Specifically, the Orthographic foil differed from the Orthographic target by only one symbol, and consequently required more finely tuned discrimination to distinguish the target from the foil (see Table 4). In the Baseline condition, by contrast, the foil was non-similar to the target, and thus required more coarsely tuned discrimination. Since false fonts carry no semantic information, only the conditions that did not require processing of meaning were presented in Experiment 2 (Baseline and Orthographic).

Results

Accuracy Results—Data from Experiment 2 were analyzed using two 4 (Grade) $\times$ 2 (Condition) repeated measures ANOVAs, one with the proportion correct as dependent variable and one using mean (untrimmed) reaction time normalized by accuracy (Efficiency scores). Accuracy results yielded a significant effect of Condition $F(1,7) = 11.95$, $p < .05$, $\eta_p^2 = 0.63$, but no significant main effect of Grade $F(3,5) = 4.03$, $p > .05$, $\eta_p^2 = 0.71$; and no significant Grade $\times$ Condition interaction $F(3,5) = 3.69$, $p > .05$, $\eta_p^2 = 0.69$ (See Table 5).

Reaction Time Results—Efficiency score results (Reaction time/Accuracy) also yielded a significant main effect of Condition $F(1,7) = 215.97$, $p < .001$, $\eta_p^2 = 0.97$, such that children responded to the Baseline condition more efficiently than the Orthographic condition (in which the symbols differed by only one letter), but also did not yield a significant main effect of Grade $F(3,5) = 1.11$, $p > .1$, $\eta_p^2 = 0.40$, or any significant interactions (Table 6).

Results from Baseline and Orthographic Conditions between Experiments 1 and 2—The amount of facilitation between Orthographic and Baseline conditions was also computed (mean Orthographic RT- Baseline RT to correct trials only) for Experiment 2, and was compared to that of Experiment 1 using non-parametric Independent Samples Mann-Whitney U tests. While the null hypothesis could not be rejected for children in grades 1 and 2, the null hypothesis was rejected in grades 3 and 4, suggesting that processing speed in grades 3 and 4 differed between Experiments 1 and 2 (See Table 7).

Discussion

The pattern of results from Experiment 2 differs from that observed in Experiment 1. In Experiment 1, words were presented in English, and results demonstrated a main effect of both Grade and Condition. Experiment 2, which presented stimuli in a false font, demonstrated a main effect of Condition, but not Grade. This result indicates that processing the false font did not improve with age, and thus strongly suggests that the improvement in orthographic processing in Experiment 1 was due to improved *reading* and not improved symbol matching, a skill which becomes qualitatively different from reading as children develop skills to recognize words directly from the orthography. There was also some evidence from Experiment 2 that early reading is similar to symbol matching, but becomes progressively dissimilar in the older grades. That is, children in first and second grade responded with more similar speed and accuracy to words and false font compared to children in the older grades (See Figure 4). This result may be due to the fact that younger children use a letter-by-letter strategy to read words (more consistent with linear models of reading), and thus for these young children, matching symbols in Experiment 2 may not have been a drastically different task from reading words in Experiment 1. For the older children who likely no longer utilize a letter-by-letter strategy for reading words, the false font condition of Experiment 2 was more difficult, and consequently was answered with longer reaction times.

It is likely that the faster reaction times observed in older children to words and not to symbols, was also due to the fact that third and fourth grade children had learned to “chunk” words into whole words or word-parts, and thus had become less focused on the individual symbols that comprise the word when reading real words. This strategy is dependent upon having a familiarity with a word and some cascaded semantic processing of the word, two strategies that would be ineffectual in a symbol search task using unfamiliar and non-meaningful symbol strings. This different processing strategy would explain the increasingly disparate results between Experiments 1 and 2 with age, and provide further evidence that children in the younger grades are more focused on the orthographic shape of the word (a perceptual component). This explanation would further suggest that while both words and symbols begin as meaningless marks on a page, with increasing exposure the symbols that become meaningful (i.e. words) come to be processed in a qualitatively different manner from novel symbols. In Experiment 2 we see that the younger children still process words and novel symbols similarly, whereas the older children have learned to process words in a different, more efficient manner, which does not generalize to the meaningless symbols.

General Discussion

Results from the present investigation indicate that developing the orthographic and semantic components necessary for skilled reading follow different developmental trajectories during reading acquisition. Strong perceptual-level skills required to efficiently form an orthographic representation precede strong conceptual-level skills required to efficiently map the orthographic representation onto a meaning. Although even the youngest readers demonstrate the ability to process both the more perceptual-level orthographic information and the more conceptual-level semantic information, results from the present investigation suggest that these processes are not yet equally efficient. These results are in

accordance with previous research that suggests that younger children rely on more concrete, perceptual systems before transitioning to more flexible, abstract cognition later in childhood (Quinn & Eimas, 1997; Rayner, 1988).

Results from Experiment 1 demonstrate a rapid increase in semantic processing efficiency in each subsequent grade. The youngest group of participants (six and seven-year-olds) demonstrated very fast, though coarsely tuned orthographic processing, and were slow to extract meaning from an orthographic representation. Children in the second grade showed fast orthographic processing (though still demonstrated some over-reliance on the perceptual, orthographic level), and also a decreased time lag to access semantic information from the text (faster access to a semantic representation). The difference in processing time between deciphering the orthographic code and accessing a semantic representation was even smaller in the third grade, and in the fourth grade there was no significant difference in reaction time between forming an orthographic and semantic representation. This suggests that by the fourth grade, the semantic processing system is just as strong as the orthographic system. Thus, the current results from children in the second, third, and fourth grades (though not the youngest, first grade readers) are consistent with 1) Connectionist, cascaded models of reading (e.g. Harm & Seidenberg, 2004; Plaut et al., 1996), in which semantic knowledge influences the decoding and lexical retrieval processes and 2) “Direct routes” of reading comprehension, in which meaning can be accessed automatically from an orthographic representation without an intermediary phonological decoding step (Coltheart et al., 2001). These older readers were also less likely to accept an orthographic neighbor as a target word, indicating finer tuned orthographic processing, consistent with the lexical tuning hypothesis (Castles et al., 2007). The youngest readers, however, showed evidence of more coarsely tuned orthographic processing and slow lexical access, which is consistent with more linear models of reading (e.g. Morton, 1969), and the phonologically mediated route of Coltheart's (2001) Dual Route model. These results suggest that there exists a transition from a phonologically mediated, indirect, linear route, to a more automatic, direct, or cascaded route, which involve semantic activation before orthographic processing is complete. The present results suggest that this transition occurs quite early; at around the third grade.

An alternative explanation for this finding is that the younger children lacked the cognitive control required to inhibit their initial response (the orthographic neighbor), and that the superior performance of the older children indexes the maturation of inhibitory mechanisms. While this possibility should be further explored, first graders' performance on the Orthographic condition (orthographic match and orthographic-neighbor foil) provides some evidence against this explanation. In the Orthographic condition, children must choose between the orthographic neighbor, and an orthographic match. Children did not demonstrate difficulty inhibiting the incorrect response to the orthographic neighbor in this condition (though it has the same degree of similarity to the target as the foil in the Orthographic-semantic condition), suggesting that it is not a lack of cognitive inhibition *in general* but rather difficulty inhibiting the perceptually similar response when it is in direct contrast with a perceptually dissimilar response option. If this is the case, the subsequent question must be *why are younger children unable to inhibit an orthographically similar*

response, yet able to inhibit a semantically similar response? Children are less likely to inhibit a more automatic response, suggesting again that semantic activation is not yet automatic in young readers, and automatic orthographic processing has already emerged (making it more difficult to inhibit). In other words, inhibiting the stronger system is more difficult, thus resulting in lower accuracy for the Orthographic-semantic condition. Although discussed within a cognitive inhibition model, rather than a reading model, this interpretation is consistent with the developmental shift from perceptual to abstract cognition.

Experiment 2 was a control condition to ensure that the orthographic processing tested in Experiment 1 was specific to reading, and did not tap a symbol matching task, unrelated to reading acquisition. Experiment 2 found that matching symbol strings and matching words was more similar for the children in the younger grades than for children in the older grades, and that children in the older grades were actually slower than those in the younger age-groups to match the symbol strings. This is the opposite pattern as that observed in Experiment 1 for reading words, in which case the older participants were faster and more efficient on every condition. Results of Experiment 2 illustrate two important findings: First, that in the older groups, reading words and matching symbols appear to tap two separable processes, as younger children perform better on the symbol matching and older children perform better on the word matching. Second, results suggest that younger children may use more of a symbol-search strategy in everyday reading, as they were able to carry those skills to the new, non-meaningful font, and rapidly and accurately identify the matching string of symbols. Children in the older grades had likely learned to chunk words, or parts of words, to recognize words as a unit. Thus the letter-by-letter search strategy was tedious and less efficient. Together results from Experiments 1 and 2 suggest that children develop orthographic processing skills very early, and create efficient links joining orthographic and semantic representations at about the third grade (around eight years of age).

Although the present investigation reports evidence that this transition occurs approximately a year later than previous studies discussed in the Introduction (namely Nation & Cocksey, 2009), the finding that automatic orthographic activation is present in early to mid elementary school years is in accordance with these previous findings. It is possible that the participant population and task may account for the slight differences observed in age. For example, in Nation and Cocksey's (2009) investigation, participants scored above average on standardized measures of reading, suggesting that this sample was slightly ahead of their peers in reading development. In addition, while the mean age of participants in Nation and Cocksey's (2009) investigation was around seven and a half years, children ranged from 6.58 to 8.75, a span of over two years, and indeed the children on the older end of this age-range were the same age as the children in the present investigation who demonstrated similar results. In view of these differences in participant demographics and age-range within groups, we believe that the results stand to corroborate, rather than contradict previous findings. Specifically, similar to the present results, investigations by Nation and Cocksey (2009), Pratarelli and colleagues (1994), and Zecker (1991), which were discussed above, all report evidence of automatic lexical access between seven and nine years of age.

The results from the present investigation add to our understanding of reading development in the elementary school years, and may have implications for reading interventions for children who struggle with reading. However, there are limitations to the applicability of the current study, which require further exploration. First of all, the results from orthographic and semantic processing are limited to the English orthography, and do not take into account orthographies that vary in the amount of grapheme to phoneme correspondence, or the amount of information represented by each orthographic symbol (e.g. phonemic, morphological, or lexical). While it is not addressed in the current study, the complexity of a language's orthography will likely impact the profile of orthographic and semantic development during reading acquisition. More research is needed to determine whether the profile of the two components of reading will differ depending on the specific orthography studied. Future research should investigate orthographies in which each orthographic symbol carries semantic meaning, to determine whether children follow the same developmental profile (orthography to semantics) when the semantic information is embedded within orthographic characters.

A second limitation to the present study is its focus on the relationship between orthography and semantics, without directly investigating the phonological component. The reason for focusing on the orthographic-semantic contrast was both logistical and theoretical. Logistically, we did not wish to use non-word stimuli, as we were interested in probing how children access *meaning* from text, yet words that have both a homonym *and* a synonym (e.g. STAIR has both a synonym *step* and a homonym *stare*) to utilize as target words are extremely scarce. Theoretically, it was the goal of the present investigation to explore reading development within a framework that views development as a shift from cognition that is dependent on perceptual, observable features, to more abstract cognition. The study of orthography (a directly observable component) and semantics (an abstract component), allowed for the results of the present investigation to be interpreted within this concrete to abstract cognitive framework.

Lastly, the design of the present investigation is cross-sectional, which is susceptible to group differences rather than developmental differences, *per se*. To ensure that the differences in grade were attributable to developmental changes, a follow-up longitudinal design should be implemented.

Conclusion

For most adults, reading is a fairly effortless process, one in which text leaps off the page and becomes an abstract concept. This may make it difficult to appreciate that reading is the result of separable cognitive processes, which children must integrate during the course of reading acquisition. The present results highlight the fact that these processes do not develop simultaneously, but rather reflect a transition from more perceptual representations (orthographic) to more conceptual representations (semantic), a shift that occurs in the early elementary school years.

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Appendix A

	<i>All stimuli</i>	Baseline		Orthographic		Semantic		Orthographic-Semantic	
	<i>Target</i>	<i>Match</i>	<i>Foil</i>	<i>Match</i>	<i>Foil</i>	<i>Match</i>	<i>Foil</i>	<i>Match</i>	<i>Foil</i>
1	BIG	BIG	TAPE	BIG	BIB	LARGE	TAPE	LARGE	BIB
2	BOAT	BOAT	GAME	BOAT	BOOT	SHIP	GAME	SHIP	BOOT
3	BUCKET	BUCKET	SCHOOL	BUCKET	BUCKLE	PAIL	SHCOOL	PAIL	BUCKLE
4	BUG	BUG	TABLE	BUG	BUS	INSECT	TABLE	INSECT	BUS
5	CAP	CAP	PIG	CAP	CAT	HAT	PIG	HAT	CAT
6	ROAD	ROAD	LIKE	ROAD	ROAR	STREET	LIKE	STREET	ROAR
7	COAT	COAT	HAND	COAT	COLT	JACKET	HAND	JACKET	COLT
8	CUT	CUT	OWL	CUT	CUB	SNIP	OWL	SNIP	CUB
9	HOP	HOP	PEN	HOP	HOT	JUMP	PEN	JUMP	HOT
10	KID	KID	BALL	KID	KIT	CHILD	BALL	CHILD	KIT
11	LADY	LADY	WATER	LADY	LAZY	WOMAN	WATER	WOMAN	LAZY
12	LATE	LATE	SPOON	LATE	LAKE	TARDY	SPOON	TARDY	LAKE
13	MAD	MAD	SHEEP	MAD	MAP	ANGRY	SHEEP	ANGRY	MAP
14	MONEY	MONEY	STOP	MONEY	MONKEY	CASH	STOP	CASH	MONKEY
15	MUG	MUG	FLY	MUG	MUD	CUP	FLY	CUP	MUD
16	PLATE	PLATE	FIRE	PLATE	PLANE	DISH	FIRE	DISH	PLANE
17	RUG	RUG	BIRD	RUG	RUN	CARPET	BIRD	CARPET	RUN
18	SEAT	SEAT	WORM	SEAT	SEAL	CHAIR	WORM	CHAIR	SEAL
19	SICK	SICK	FROG	SICK	SINK	ILL	FROG	ILL	SINK
20	SMALL	SMALL	APPLE	SMALL	SMELL	LITTLE	APPLE	LITTLE	SMELL
21	STAIR	STAIR	GIRL	STAIR	STAIN	STEP	GIRL	STEP	STAIN
22	STONE	STONE	EARS	STONE	STOVE	ROCK	EARS	ROCK	STOVE
23	GUY	GUY	PILE	GUY	GUM	MAN	PILE	MAN	GUM
24	LOOK	LOOK	BARN	LOOK	LOCK	SEE	BARN	SEE	LOCK
25	SHOVE	SHOVE	BATH	SHOVE	SHORE	PUSH	BATH	PUSH	SHORE
26	LEAVE	LEAVE	POOL	LEAVE	LEASE	EXIT	POOL	EXIT	LEASE

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Figure 1.

displays the four experimental conditions. Each box represents the screen for one trial.

Condition A contains an orthographic match and an unrelated foil, condition B contains an orthographic match and an orthographic neighbor as a foil, condition C contains a semantic match, and an unrelated foil, and condition D contains a semantic match and an orthographic neighbor as a foil.

Figure 2. Displays efficiency scores (reaction time/accuracy) by grade for all conditions. Results are displayed with standard error bars.

Figure 3.

Displays the mean reaction time to Orthographic minus Baseline (hatched) and Semantic minus Baseline (solid) for correct trials only in Experiment 1. Results are displayed with standard error bars.

Figure 4. compares the mean Reaction Times to correct trials only in the Orthographic condition between Experiment 1 (stimuli presented in the English orthography) and Experiment 2 (stimuli presented in a false font). Results are displayed for the first through fourth grade with standard error bars.

Table 1

Example of stimuli counterbalancing across items and participants.

Baseline			Orthographic			Semantic			Orthographic-semantic		
Target	Match	Foil	Target	Match	Foil	Target	Match	Foil	Target	Match	Foil
S1	SICK	SICK	FROG	BOAT	BOAT	SMALL	LITTLE	APPLE	STONE	ROCK	STOVE
S2	BOAT	BOAT	GAME	SICK	SICK	STONE	ROCK	EARS	SMALL	LITTLE	SMELL
S3	SMALL	SMALL	APPLE	STONE	STONE	SICK	ILL	FROG	BOAT	SHIP	BOOT
S4	STONE	STONE	EARS	SMALL	SMALL	BOAT	SHIP	GAME	SICK	ILL	SINK

* S: Student number

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Table 2

Experiment 1 accuracy results.

Grade	Baseline		Orthographic		Semantic		Orthographic-Semantic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	.96	.08	.85	.22	.79	.22	.43	.41
2	1.0	0	.95	.09	.96	.07	.75	.22
3	.99	.03	.97	.09	.98	.06	.87	.13
4	1.0	0	.99	.03	.97	.07	.91	.10

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Table 3

Experiment 1 mean reaction time results (in seconds) to correct trials only.

Grade	Baseline		Orthographic		Semantic		Orthographic-Semantic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	2.70	.87	3.12	1.10	7.28	6.35	6.52	7.31
2	2.13	.50	2.63	.93	3.63	1.97	3.71	1.29
3	1.92	.43	2.12	.56	2.52	1.19	2.62	.73
4	1.80	.43	2.04	1.05	2.11	.56	2.48	1.09

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Table 4

Stimulus example for Experiment 2.

Condition	Experiment 1			Experiment 2		
	Target	Mean	Foil	Target	Mean	Foil
Baseline	SMALL	SMALL	APPLE	ʒ<U ʒ<u ʒ<u	ʒ<U ʒ<u ʒ<u	ʒ<U ʒ<u ʒ<u
Orthographic	SMALL	SMALL	SMELL	ʒ<U ʒ<u ʒ<u	ʒ<U ʒ<u ʒ<u	ʒ<U ʒ<u ʒ<u

Table 5

Experiment 2 accuracy results.

Grade	Baseline		Orthographic	
	Mean	SD	Mean	SD
1	.99	.03	.83	.19
2	.99	.03	.91	.09
3	1.0	0	.99	.03
4	1.0	0	1.0	0

Table 6

Experiment 2 efficiency score results (reaction time/accuracy).

Grade	Baseline		Orthographic	
	Mean	SD	Mean	SD
1	3.09	.70	4.10	1.26
2	3.63	.96	4.60	1.07
3	3.33	.99	5.31	1.31
4	3.21	.77	5.08	1.49

Table 7

Amount of orthographic facilitation (RT to Orthographic – Baseline) for real words (Experiment 1) relative to false fonts (Experiment 2), correct trials only.

Grade	Experiment 1	Experiment 2	Facilitation (seconds)
	Orthographic (O) – Baseline (B)	Orthographic (O) – Baseline (B)	E2 (O – B) – E1 (O – B)
1	.42	1.01	.59
2	.50	.97	.47
3	.20	1.98	1.78
4	.24	1.87	1.63