ANALYSIS OF ORTHOGRAPHIC KNOWLEDGE AND ITS RELATIONSHIP TO NAMING SPEED, PHONOLOGICAL AWARENESS, AND SINGLE WORD IDENTIFICATION

by

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Abstract

Past reading acquisition research has provided support for the hypothesis that sensitivity to the sound structure of words (phonological skill) is related to the development of effective orthographic (letter-pattern) processing (Ehri, 1992). The experiment reported here examined the hypothesis that quick and efficient access to letter codes might also be related to the development of orthographic abilities. A new measure of orthographic awareness, based on differential reaction time to high and low frequency letter patterns, was developed. The emergence of children's sensitivity to orthographic structure was examined among children in grades 1, 2, and 3, using the new measure and two more conventional ones.

Results indicated that depending on the orthographic measure used, children began demonstrating a sensitivity to orthographic structure by grade 2 or 3. Furthermore, rapid naming speed (assessing quick access to letter codes) as well as phonological skill were related to a number of the orthographic tasks. Orthographic task differences are discussed in an attempt to explain rapid naming speed's varying degree of contribution to these measures. Finally, rapid naming speed's contribution to word identification, beyond its contribution to orthographic knowledge, is explored.

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Introduction

Stanovich (1992) has developed an influential model concerning the individual differences contributing to the acquisition of reading skills. One aspect of his model, the individual differences associated with orthographic skill, is reconceptualized in this thesis and its usefulness assessed. The model described by Stanovich and others will initially be described followed by the proposed reconceptualization.

First, in his discussion of the potential causes and consequences of individual differences in early reading acquisition, Stanovich (1992) cites the abundance of research which reports that sensitivity to speech sounds within words (phonological sensitivity) ranks as one of the most significant predictors of early reading achievement (e.g., Liberman, 1983; Mann, Tobin, & Wilson, 1987; Share, Jorm, Maclean, & Matthews, 1984; Stanovich, Cunningham, & Cramer, 1984; Tunmer & Nesdale, 1985; Vellutino & Scanlon, 1987; Wagner & Torgesen, 1987; Yopp, 1988).

Although a causal connection between phonological knowledge and initial reading development cannot be established from the above correlational findings, Stanovich (1992) reviews a body of research that suggests the existence of such a relationship, since significant gains in reading, word recognition, and spelling resulting from sessions of phonological skill training were demonstrated (e.g., Cunningham, 1990; Fox & Routh, 1984; Lundberg, Frost, & Petersen, 1988; Olofsson & Lundberg, 1985, Treiman & Baron, 1983). While these findings suggest that phonological knowledge causally contributes to reading achievement, Stanovich (1992) subsequently introduces the findings of Ehri (1979, 1984, 1985; Ehri, Wilce, & Taylor, 1987) as well as Perfetti, Beck, Bell, & Hughes (1987) which suggest that gains in reading achievement may promote the development of phonological knowledge. In short, current research findings appear to indicate that the connection between phonological knowledge and initial gains in reading may be reciprocal in nature.

Stanovich (1992) then asserts that if phonological processing is so strongly connected to early reading gains, perhaps there is no need to investigate alternate forms of cognitive processing associated with reading skill development. Such a claim would be reasonable if all children with strong phonological skills were able to master reading with ease. This, however, is not the case. For example, Juel, Griffith, and Gough (1986) and Tunmer and Nesdale (1985) demonstrate that proficiency at phoneme segmentation, although necessary, is not sufficient to ensure quick reading gains. In short, although children with weak phonological knowledge rarely develop reading skill quickly, those with strong phonological abilities are not necessarily destined to become proficient readers.

What might be an additional factor accounting for reading skill development? Reitsma (1983) has suggested that reading disabled (RD) children have deficits in the ability to form orthographic representations. In this seminal 1983 study, grade 1 beginning readers and RD children who were two years older than the first grade students yet matched with them on reading level were given varying amounts of practice in reading a set of unfamiliar words. Over a span of two consecutive days, all children practised reading sentences with these words either 2, 4 or 6 times. Three days later, response times to read the originally practised words as well as a second set containing similar sounding nonwords were recorded. Results indicated that 4 trials of practice was sufficient to produce faster response times for the practised words compared to the previously unseen nonwords. Interestingly, this result was present for the beginning readers and not the RD children. The latter did not demonstrate a speed advantage for the recognition of practised words versus unpractised words even after 6 trials of prior exposure. These findings suggest that less skilled readers seem to have difficulty forming visual-orthographic representations. Using a similar procedure, Ehri and Saltmarsh (1995) replicated these results offering further support to the Reitsma findings.

Before continuing, it is important to review what is meant by an orthographic representation. First, an orthographic representation refers to the coded visual features of letters and letter sequences in words (Stanovich, 1992). Furthermore, accessing a word's orthographic representation allows word recognition to occur directly from text rather than from the implementation of a decoding or "sounding out" procedure. Thus, the beginning readers in Reitsma's study could recognize the practised words by "sight" faster than they could decode the unpractised homophonic spellings.

To summarize, the findings of Reitsma (1983), as well as other work by Ehri and Saltmarsh (1995), suggest that a specific inability to form and recognize orthographic representations of words is an area of weakness for less skilled readers in addition to their phonological difficulties.

What might be contributing to this orthographic skill deficit among reading disabled children? Ehri (1992) suggests that these children's poor phonological decoding contributes to their deficits in orthographic processing. This conclusion is based upon Ehri's two stage model of word recognition. Specifically, Ehri (1992) proposes that stage 1 involves phonological decoding of individual letters whereby letter-sound correspondences are used to decipher word pronunciation. Stage 2 consists of a visual-phonological sight route whereby the word's pronunciation is accessed directly from the visual characteristics of the word's spelling. Ehri (1992) suggests that once a word has been phonologically decoded several times (stage 1), a direct connection is formed between a word's visible spelling and its pronunciation. "It is this amalgam that is accessed directly when sight words are read and recognized by means of visual-phonological connections" (Ehri, 1992, p. 120). Based upon this theoretical framework, Ehri (1992) concludes that the less skilled reader's weak phonological skill thwarts the development of his/her orthographic processing skill. In short, poor phonological sensitivity hinders the establishment of explicit orthographic representations.

Cunningham and Stanovich (1990) and Stanovich and West (1989) have positions consistent with Ehri (1992) in that their theories also emphasize the importance of phonological sensitivity for establishing orthographic skill; however, they make the additional claim that print exposure (an estimate of individual differences in amount of previous reading activity) contributes uniquely to orthographic variance even after controlling for phonological skill. An indirect measure of print exposure was obtained by having adults review a list of people's names and place check marks to indicate familiarity with the names of popular authors (Author Recognition Test - ART). This measure is considered indirect as it can only serve as a "proxy measure" of reading activity. The underlying assumption concerning the ART is that individuals who recognize the names of popular authors are likely to have read more material than individuals who do not recognize such names. To reduce the likelihood that scores could be inflated due to guessing or social desirability effects, half the items were foils consisting of names of people who are not popular authors. A Magazine Recognition Test (MRT) was also used which utilized magazine titles instead of author names. All other characteristics were similar to the ART. Finally, a similar type of task was developed for children using titles of children's books. Results indicated that those subjects who had greater reading exposure, as indexed by these tests, were faster at identifying the real word within a pair of visually displayed letter strings that sounded alike (e.g. lurn, learn), a commonly used test of orthographic knowledge. Even after controlling for phonological decoding skill, individuals with greater print exposure demonstrated a greater knowledge of orthographic patterns.

In summary, Ehri (1992), Cunningham and Stanovich, 1990; and Stanovich and West (1989) confirm the view that poor letter-sound knowledge and limited print exposure both contribute significantly to the difficulty that less skilled readers have in forming visual-orthographic representations. Given this conclusion, the question remains whether these two factors, phonological processing ability and print exposure, account for all the individual differences seen in the formation of visual-orthographic representations.

The answer to this question appears to be "no". Both Cunningham and Stanovich (1990) and Stanovich and West (1989) report that not all the variance associated with orthographic processing ability is exhausted by phonological skill and differences in print exposure. Given their findings of unaccounted variance in predicting orthographic functioning, what else might be contributing to the independent orthographic variance? In trying to answer this question, Stanovich (1992) and Stanovich and West (1989) refer to

Frith's (1985) view which states that.

> "Precise orthographic representations are acquired as the result of a reading strategy that gives equal attention to all letters in a word... Such a strategy would therefore involve more work than was necessary and sufficient for word recognition. It is conceivable that individual differences exist in terms of willingness/capacity to adopt such a wastefully inelegant strategy, and this would provide an explanation for arrest at this point in the sequence" (pp. 320-321).

In short, in addition to poor phonological processing skill and lower print exposure, Frith contends that a superficial and nonanalytic reading "style" may also contribute to the differences one sees in orthographic processing ability.

However, an alternate perspective emphasizing a "cognitive ability" formulation rather than a "style" interpretation, as proposed by Frith, is introduced to explain individual differences. Specifically, it is hypothesized that the "ability" to name letters rapidly may strongly influence the development of orthographic processing ability (Bowers & Wolf, 1993; Golden & Bowers, 1993).

How might naming speed for visually presented letters be theoretically linked to children's sensitivity to orthographic structure? To address this question, the present study has adopted the theoretical model of orthographic redundancy proposed by Adams (1979, 1981). While the present research does not attempt to empirically test this model, its explanation of the means by which young readers' develop awareness of orthographic structure provides a framework for the proposed link between naming speed (automaticity) and orthographic knowledge.

According to Adams's (1979, 1981, 1990) model of orthographic redundancy, orthographic awareness (becoming sensitive to the orthographic structure of written material) is said to develop as a result of prior exposure to particular letter sequences. When a skilled reader encounters a word, each letter is not recognized independently. Rather, the recognition of individual letters become connected to one another in varying degrees. To illustrate, let us consider the letter *T*. All letters that have previously been seen together with this letter will be indirectly activated. The degree of activation will be dependent upon the extent to which these letters have previously co-occurred with the letter *T* in print. Conversely, all letters that have rarely been seen with the letter *T* will be inhibited. The degree of inhibition will be dependent upon the rareness of their co-occurrence (Adams, 1981, 1990; Seidenberg & McClelland, 1989).

With greater reading experience, associations develop beyond single ordered pairs of letters (bigrams). As text becomes more familiar, letter associations begin to encompass whole common words. Finally, associations develop such that the reader becomes sensitive to frequent spelling patterns embedded within larger words (Adams, 1990).

An underlying assumption of this theoretical framework is that readers must visually process each individual letter of the word they are reading. Without such attention, the child will never begin to form the integral associations between letters that arise from first recognizing their co-occurrence in text (Adams, 1990). This orthographic redundancy model of Adams (1981) may be used to support the theoretical connection between the speed with which children can name visually presented letters, and their increasing awareness of orthographic structure. If single letter identification is slow, by the time a reader begins identifying the second letter encountered in a letter string, the stimulation of the unit responsible for the recognition of the first letter may have already faded. The longer it takes a child to resolve the individual letters of a word, the less information he/she will be able to abstract regarding the specific spelling of that word or, more generally, the common associations between letters (Adams, 1981, 1990).

Consistent with this interpretation, Blachman (1984) demonstrated that grade 1 children who could rapidly name an array of high frequency lowercase letters were most likely to be among the better readers, as indicated by letter speed and reading achievement correlating .67. The Rapid Automatized Naming Test, or RAN, introduced by Denckla and Rudel (1974, 1976), was utilized by Blachman (1984) to index naming speed. The letter arrays consisted of five high frequency letters (o,a,s,d,p) displayed in random order. Letters were arranged in five horizontal rows, each row containing ten letters. In the traditional Denckla and Rudel (1974) paradigm, items can include either high frequency letters, numbers, pictures of objects, or colour patches.

A review of the naming speed literature generally reveals that strong relationships exist between slow levels of continuous naming speed and poor reading skill (e.g., Denckla & Rudel, 1976; Spring & Davis, 1988; Spring & Perry, 1983; Wolf, 1991). Furthermore, Biemiller (1977-1978) reported that while younger and less able children were slower to read words than letters, older and abler readers read words in the same amount of time as letters. Such findings are consistent with the Adams's (1981) model of orthographic redundancy in that less able readers' slow letter naming speed might have prevented the establishment of associative connections between commonly occurring letter clusters in text and necessitated a more tedious serial processing of individual letters within words. Conversely, the more proficient readers' faster naming speed was perhaps sufficiently quick to allow them to begin processing certain letter clusters as units after being exposed to these same letter sequences in text, perhaps increasing parallel processing of letters in these units. Reducing the overall number of individual letters processed serially within each word would thus decrease the time taken to identify the word as a whole. Once the entire word was able to be processed as a single unit (or in parallel), reading the whole word could then be carried out in the same time it would take to identify an individual letter.

While the naming speed literature has examined the relationship between speed of letter naming and reading achievement, Berninger, Yates and Lester (1991) examined the relationship between reading ability and the identification of orthographic letter-cluster units. Children in grades 1, 2 and 3 were first visually presented a high frequency target word for 1 second (e.g., them) which was taken from the Carroll, Davies, and Richman (1971) grade 3 word-frequency tables. After the target word exposure, subjects were then shown a display of either a whole word (e.g., them), a single letter (e.g., m), or a letter-cluster (e.g., em) and asked to determine whether the display string matched or contained letter items present in the target word. Results indicated that children were most accurate for the whole word match condition, less accurate for the single letter task, and least accurate for the letter-cluster task. Despite the letter-cluster task's difficulty, it was the best predictor of reading ability in comparison to the other two measures.

Given the relationship between letter cluster sensitivity and reading ability demonstrated by Berninger et al. (1991), Golden and Bowers (1993) examined the association between naming speed, reading skill, and developmental changes in the recognition and use of letter-cluster orthographic codes. Employing the Berninger et al.

(1991) paradigm, each of 43 children from grades 1, 2 and 3 carried out three orthographic coding tasks. Each child was shown a target word followed by the display of either a whole word, a single letter, or a letter-cluster that either matched or was present in the originally seen target word, for the "yes" condition, or did not match or was not present in the "no" condition.

Consistent with the Berninger et al. (1991) result, performance on the letter-cluster task was the best predictor of reading ability in the "yes" condition after controlling for grade level. This relationship was not present in the "no" condition. Compared to the "yes" condition, the "no" condition appears to require greater memory resources, as a child must retain the initial target word in memory while conducting a search for the subsequently presented letter-cluster. In contrast, the "yes" condition seems to involve a more direct and cognitively less demanding orthographic match between target word and subsequent letter-cluster. The finding that letter-cluster performance in the "yes" condition was a better predictor of single word identification than performance in the "no" condition is consistent with the direct orthographic matching process required in this condition. Our finding that "yes" and "no" letter-cluster conditions were not correlated with each other is further evidence that these two conditions involve different underlying processes.

Of special interest to this thesis was the question of whether or not individual differences in naming speed would be associated with differences in the children's ability to detect letter clusters. Previous results indicated that children's ability to rapidly name digits on the RAN was significantly correlated with letter-cluster recognition as well as single word identification as measured by the Word-Identification (WID) subtest from the

Woodcock-Johnson Psycho-Educational Battery-Revised (Golden & Bowers, 1993). Interestingly, individual differences in RAN added no unique variance to WID after controlling for letter-cluster performance. Given the extremely high correlation between letter and digit naming speed (Bowers & Wolf, 1993), such findings suggest that children's ability to rapidly recognize and name a letter might contribute to their sensitivity to letter-cluster orthographic patterns, the more proximal associate of word reading skill. As described earlier, if individual letter identification is slow, single letters in a word may not be activated quickly enough to allow for the child to become sensitive to letter patterns that frequently co-occur in text. The longer it takes the child to resolve the individual letters of a word, the less information he/she will be able to abstract regarding the specific letter clusters in that word (Adams, 1981, 1990).

Consistent with Ehri (1992), Golden and Bowers (1993) also demonstrated that individual differences in phonemic awareness, as measured by a phoneme deletion task, contributed a significant amount of unique variance to letter cluster performance (indexing sensitivity to orthographic structure). Of importance to this investigation, however, they demonstrated that rapid digit naming also added unique variance to letter-cluster performance. Such findings offer additional support to the speculation that naming speed differences between readers are strongly associated with the formation and use of letter-cluster orthographic codes.

To summarize, various researchers have provided support for the claim that poor phonological decoding skills and limited print exposure impede the development and formation of visual orthographic representations (Cunningham & Stanovich, 1990; Ehri, 1992; Stanovich & West, 1989). However, the research described above indicates that phonological processing skill and print exposure do not exhaust all the reliable variance associated with processing information orthographically. Based upon the findings of Golden and Bowers (1993), it is proposed that slow access to letter codes is significantly related to the delayed development of both orthographic processing and the subsequent automatic recognition of individual words.

Overview of Present Research

In order to test the naming speed hypothesis, I first set out to identify the development of orthographic awareness skill among children in grades 1, 2, and 3 who represented the broad spectrum of readers found in a regular class. Demonstrating the emergence of children's sensitivity to orthographic structure is a prerequisite for understanding the possible determinants for its development.

The study of the development of orthographic awareness skill had precedent in our previous effort to examine growth in phonological awareness across children in Kindergarten, grade 1, and 2 (Golden & Bowers, 1992). That work showed that identifying the number of syllables in a word was the only task mastered by Kindergarten students. Among the grade 1 and 2 students, accuracy was highest on a phonological blending task and lowest on a phoneme deletion exercise as measured by the Auditory Analysis Task (Rosner & Simon, 1971).

As previously described, the first objective of the present study was to assess the developmental course of orthographic awareness. However, based upon the Golden and Bowers (1992) finding that children's performance on various measures of phonological awareness differed by task as well as by age, it seemed reasonable to ask whether different measures of orthographic awareness might also show different effects based on age.

Orthographic awareness has been operationalized in numerous ways. The most common is the orthographic choice task used by Olson and his associates (e.g., Olson, Kliegl, Davidson, & Foltz, 1985; Olson, Forsberg, & Wise, 1994). In this task, participants are presented with a printed word (salmon) and a printed pseudohomophone (sammon), and are requested to chose the one that is the real word. Stanovich and West (1989) varied this task slightly by asking participants to chose one of two homophones after being given information that defines one of them. For example, participants heard the question, "which is a fruit?", followed by the visual presentation of "pair/pear".

Another popular approach for assessing orthographic skill has been the implementation of a "letter string choice", or "word likeness task" (e.g. Rosinski & Wheeler, 1972; Siegal, Share, & Geva 1995). In these tasks, participants are visually presented a pair of letter strings and asked to chose the one that is most "word like" (e.g., nuck, ckun).

Horn and Manis (1985) have employed yet another type of orthographic awareness measure. They presented individual words and pseudowords varying in degree of orthographic structure (high and low) followed by a target letter to be identified as present or absent in the previous "word" display by pressing a "yes" or "no" button. Juola et al. (1978) adopted a similar procedure to Horn and Manis but reversed the order of presentation of the letter target and word display. Specifically, they presented a target letter prior to displaying either a common word (best), a regular pseudoword (steb), or an irregular nonword (tbes). Finally, Chase and Tallal (1990) also used a visual search paradigm similar to Horn and Manis. They initially presented either a word, pseudoword, or nonword to participants. After removal of the target, they then presented a pair of letters in a specific position and asked individuals to indicate which of the two letters had been presented in that position.

Concerns Regarding such Definitions of Orthographic Processing

Vellutino, Scanlon, and San Chen (1995) argue that the various measures of orthographic awareness may possibly assess either word identification or spelling ability rather than orthographic coding per se. For example, they argue that orthographic tasks that contain real words might simply be distinguishing between children who can read presented words versus those who cannot. Furthermore, they claim that among children who cannot accurately identify such words, these measures offer minimal information concerning the manner in which developing readers code orthographic information.

In response to some of these concerns, I developed a new orthographic task to identify the growth of children's sensitivity to orthographic structure. This procedure adopts a visual search paradigm used by Juola, Schadler, Chabot, and McCaughey (1978), with stimuli altered for the task of assessing orthographic development. Rather than ask participants to search for a single letter in either a word, pseudoword, or nonword, as was previously done, children were asked to search for a single letter in a display that consisted of either a single letter, a nonword bigram, or a nonword trigram. Nonword or sublexical letter strings were used in an attempt to reduce the "word" identification component of the visual search task, thus addressing the concern with previous studies raised by Vellutino et al. (1995). Furthermore, presenting the single letter target prior to the presentation of the single, bigram or trigram display reduces possible word identification effects. For example, it seemed reasonable to assume that having letter strings following the initial target letter required only a single letter to be kept in mind before processing the letter string, a task both skilled and unskilled readers can accomplish by grade 3. It was for this reason that the Juola et al. (1978) experimental procedure was adopted rather than the Horn and Manis (1985) method which presented the word or pseudoword display prior to the presentation of the single target letter.

Although Vellutino contends that most orthographic measures offer minimal information concerning the manner in which developing readers code orthographic information, the measure developed for this study attempts to provide a metric for tracking such development. Displays of various sizes were introduced (single letters, bigrams, and trigrams) to try and assess the developmental path associated with increasing the size of orthographic units. Finally, in developing the stimuli for the new orthographic task, each of the three types of target displays were developed to contain both high and low summed letter frequency values based upon Mayzner and Tresselt's (1965) and Mayzner, Tresselt, and Wolin's (1965) frequency tables. Mayzner and Tresselt (1965) based their tables on a sample of 20,000 words chosen from a wide variety of newspapers, magazines, fiction, and nonfiction books. Their tables included single letter, bigram, and trigram frequency counts broken down for all word-length and letter-position combinations, for words three to seven letters in length. Summed letter frequency values represented the summed single letter, bigram, or trigram frequency counts for all the word-length and letter-position combinations in the Mayzner and Tresselt word sample. Experimental stimuli for the newly developed sublexical frequency task were categorized as high or low frequency based upon these summed letter frequency counts.

In conclusion, a sublexical frequency task was developed in order to identify the approximate grade level at which children begin to display orthographic sensitivity to low and high frequency stimuli. The task reflects the degree to which responses are facilitated by high frequency letter patterns and/or are inhibited by low frequency patterns.

The "frequency effect" evaluated in this paradigm is theoretically related to a phenomenon initially studied in a university student population known as the Word Superiority Effect (WSE). WSE refers to the faster identification of a letter embedded in a word contrasted to a letter presented alone (Reicher 1969). Krueger (1970) and Novik, and Katz (1971) demonstrated that adult participants were faster at searching for a given target letter within a list of words rather than a list of random letter strings. Among children, Mason (1975) demonstrated that good grade six readers are faster to identify the presence of a target letter within a high frequency letter string than a low frequency string. Poor readers did not demonstrate this high frequency response advantage. Consistent with these results, Juola et al. (1978) reported that the youngest children in their sample took the same amount of time to search for a single letter in either a common word, regular pseudoword, or irregular nonword. These findings suggest that the kindergarten students within their sample were processing all types of stimuli in a similar letter by letter fashion. However, search times for target letters among the older participants were faster for the word and pseudoword displays than for the nonwords. The combined findings of these two studies suggest that the ability of older and more proficient readers to process letters embedded in higher frequency strings faster than letters found in lower frequency strings (WSE) is an indication of their more developed sensitivity to orthographic redundancy.

Alternate Measures of Orthographic Awareness

In addition to the newly developed sublexical frequency task described above, two other measures of orthographic awareness were also used in the present study. Although I will presently review the possible difficulties associated with these tasks, they were nevertheless administered because of their established use in past research, the importance for replicating past orthographic findings, as well as the need to compare the developmental course of orthographic processing among alternate measures of this construct.

The first alternate measure of orthography was the letter-cluster task originally developed by Berninger et al. (1991) and later used by Golden and Bowers (1993). This task requires the experimenter to present a high frequency target word for one second. Children are then shown a 2 or 3 letter display and asked to determine whether the letter-cluster was present in the initially presented word. As described earlier, one possible difficulty with this task is based upon the uncertain impact of the child's familiarity with the initially presented word. That is, a child who is able to read the word easily might be more skilled at keeping the word in memory while determining whether the subsequently presented letter-cluster was present or not.

The second alternate measure of orthography was a lexical decision task similar to the one used by Rosinski and Wheeler (1972). Children were asked to chose which item among a pair of letter strings looked "more like a word". Based upon the stimuli introduced by Massaro. Taylor. Venezky. Jastrzembski. and Lucas (1980). one of the letter strings within each pair had a high summed letter frequency and was "regular" in construction (e.g., blayer), whereas the second had a low summed letter frequency and was "irregular" in construction (e.g., rbleya). One possible difficulty with this task is the apparent difference in pronouncibility between the two letter strings for each pair. Given that children are allowed to proceed through the task at their own pace, it is possible that some individuals could base their "word likeness" decision more upon their ability to pronounce the item rather than on any differences in letter-based orthographic structure.

Within the word likeness and letter-cluster tasks. the development of orthographic skill was determined by assessing changes in accuracy scores among children in different grades. Within the sublexical frequency task. the development of orthographic skill was assessed by examining the change in children's response times as a function of changes to letter pattern frequency.

While recognizing the potential difficulties with the letter-cluster and word likeness tasks. these two measures. in addition to the sublexical frequency task, are used in the current study to identify the age at which children begin to display elements of orthographic sensitivity. The fact that letter-cluster and word likeness type tasks have been used so widely in past research allows the results of this study to be linked to previous work. Moreover. using different measures of the same construct will help us examine whether differences in performance exist depending on the specific measure of orthography used.

Once establishing the general existence of orthographic sensitivity among a sub-group of children in the current study, subskills contributing to orthographic skill were investigated. Consistent with Adams's model of orthographic redundancy, it was hypothesized that rapid naming speed as well as phonological awareness skill would both contribute unique variance to orthographic skill. Given that current research emphasizes the unique contributions of both phonological and orthographic skill to word identification (see Olson et al., 1994; Wagner & Barker, 1994), efforts were undertaken to examine whether rapid naming's contribution to word identification would be fully accounted for by its hypothesized relationship to orthographic awareness, or instead contribute variance to word recognition beyond its contribution to orthographic knowledge. Golden and Bowers (1993) report preliminary support for the hypothesis that orthographic awareness subsumes rapid naming's contribution to reading. That is, they showed individual differences in rapid naming speed added no unique variance to word identification after controlling for letter-cluster performance.

Method

Subjects

A total of 84 children from grades 1, 2, and 3 participated in the study. There were 28 students per grade. Recruitment involved describing the study to children in all 3 grades and sending information letters and consent forms to parents. Children's acceptance into the study did not rely upon any criterion-based selection procedures other than fluency in English.

Measures

Orthographic Awareness Measures

The orthographic skill measures included the sublexical frequency task, a letter-cluster task, and a word likeness task. Stimuli and instructions for all three orthographic measures are listed in Appendix A.

Sublexical Frequency Task. The **sublexical frequency task** required children to decide whether an initially presented single letter matched a subsequently displayed single letter, an element of a nonword bigram, or an element of a nonword trigram.

An Amiga 500 computer with a Commodore model 1084 Colour Video Monitor was used for the administration of this task. Children were instructed to rest the first finger of their dominant hand on the "yes" key, and the same finger of their nondominant hand on the "no" key. When the display item contained a previously seen target letter, they were to press the "yes" key. When it did not, they were to press the "no" key. Speed and accuracy measures were recorded by computer. Stimuli were always displayed at the centre of the monitor. The task was administered under both speeded and unspeeded conditions.

Similar to the Juola et al.'s (1978) visual search paradigm, the unspeeded condition began with the presentation of a 250 millisecond (ms) fixation dot, followed by a 1500 ms single target letter, followed by a 500 ms pattern mask, followed by another 250 ms fixation dot, and ending with the presentation of either the single letter, bigram, or trigram display. The final display remained on screen until the child responded by pressing either the "yes" or "no" button. The speeded condition was identical to the unspeeded condition with the exception that for the speeded condition, the final display remained on screen for only 200 ms followed by a "?" symbol until the child responded. This condition was introduced to investigate how the implementation of a "time stressor" would affect performance on the orthographic frequency task. This question was posed in response to the findings presented by Yap and van der Leij (1993). Specifically, Yap and van der Leij (1993) introduced a speeded component to a lexical decision task. They displayed a word or pseudoword for 200 ms and had children respond whether the item they saw was an actual word or not. Yap and van der Leij reported that dyslexics tended to have difficulty accurately making the word/pseudoword discriminations in the speeded condition but not in the unspeeded one. They cautiously suggested that dyslexics may therefore have an automatization deficit which does not pertain solely to phonological decoding skills.

For all 3 conditions of the sublexical frequency task (single, bigram, and trigram), participants were given 5 practice trials on index cards, and 6 practice trials on the computer. The single letter condition contained 24 experimental trials since only 12 letters were categorized as high frequency items and the remaining 12 considered low frequency. Nonword bigram and trigram conditions contained 32 trials. Trials were divided evenly into display items containing high and low summed frequency values (Mayzner & Tresselt. 1965: Mayzner et al., 1965). Half the total number of trials required "no" responses. and half required "yes" responses. A "no" response was designed to occur when a match between the target letter and subsequent display did not exist. A "yes" response was required when a match was present. Two separate stimulus sequences were used such that each display occurred equally as often in a "yes" as well as a "no" trial. Within single. bigram. and trigram conditions, the presentation of high/low frequency items and yes/no response types was randomized. Finally. across all bigram and trigram test stimuli. target letters occurred approximately equally often at each of the 2 or 3 positions in the letter string.

Letter-Cluster Task. The **letter-cluster task**, based upon the Berninger et al. (1991) procedure, was presented on paper. Using a 3-ring binder. the experimenter displayed a target word printed on a single page for approximately 1 second. On the next page, the child was then shown a letter cluster, consisting of 2 or 3 letters, that was either present in the originally seen target word, for the "yes" condition, or was not present for the "no" condition. Three practice trials were initially conducted to ensure the child understood the task. Forty-two experimental trials followed. Trials were equally divided between "yes" and "no" response types and randomly presented. Accuracy alone was recorded for this task. Berninger has administered the letter-cluster task in both computer and paper forms. Results do not vary between the two methods of administration (Berninger et al., 1991).

Word Likeness Task. Finally, the **word likeness task**, based upon the Rosinski and Wheeler (1972) procedure, was administered using paper and pencil. Specifically, each child was shown a pair of letter strings and asked to circle the one that looked "more like a word". While all pairs were printed on a single page, each one was uncovered by the Experimenter as the child progressed down the list. Four practice trials were completed followed by 20 pairs of experimental items. Actual stimuli were adopted from Massaro et al. (1980). One of the items within the pair contained letters with a high summed letter frequency and was "regular" in construction, whereas the second had a low summed letter frequency and was "irregular" in construction. Accuracy alone was recorded.

Phonological Awareness Measure

The **Auditory Analysis Task** (AAT), a phoneme deletion measure, was used to assess phonological awareness (Rosner & Simon, 1971). This test has been used extensively to assess children's phonological skills (Yopp, 1988). For the AAT, children were required to repeat an orally presented word. They were then required to delete one of the phonemes, (e.g., say "block" - now say it again without the /b/). Two practice trials were initially administered and assistance offered if incorrect. A total of 29 items followed. Given the relatively young age of the children in the present study, the most difficult category of stimuli developed by Rosner and Simon was not administered. Test items and instructions for the currently used AAT are presented in Appendix B.

Letter Naming Speed Measure

The **rapid automatized naming test for letters** (RAN-L) was the naming speed measure used in the present study. Based upon Denckla and Rudel (1974), the RAN-L task consisted of a chart containing 5 lower case letters (p, o, d, a, s) repeated randomly 50 times. Items were printed in five rows containing 10 letters per row.

The original 5 letters were initially presented to the child to ensure they could be recognized and named accurately. The child was then instructed to name, as quickly as possible, each letter on the chart without stopping. The RAN-L was administered at the start of the first session and then again at the end of the same session. These two performances were averaged and indexed by the number of letters named per second. The letters and layout of the RAN-L chart is presented in Appendix C.

Word Recognition Measure

Word recognition ability was assessed using the **Word-Identification** subtest from the Woodcock-Johnson Psycho-Educational Battery-Revised (Woodcock & Johnson, 1989). The subtest required children to read aloud a list of words that progressively increased in difficulty. Raw scores reflected the number of accurately identified words and were converted to standard scores based upon the test's standardization sample. Items contained in the Word-Identification subtest are presented in Appendix D.

Procedure

Two testing sessions were conducted with each child. Each child was individually seen in a testing trailer parked on school property. Session 1 included the two administrations of the RAN-L, the "unspeeded" sublexical frequency task, the letter-cluster task, and the word likeness task. During the administration of the sublexical frequency task, the single letter condition was always the first condition to be presented. However, in an attempt to reduce order effects, half the participants then received the bigram condition followed by the trigram condition, whereas the remaining half received trigram followed by bigram. The order of presentation among all three orthographic measures was also counterbalanced to some extent. Specifically, as the letter-cluster task and sublexical frequency task were the most similar, half the children received 1) letter-cluster, 2) word likeness, and then 3) sublexical frequency, whereas, the remaining children received 1) sublexical frequency, 2) word likeness, and then 3) letter-cluster.

Session 2 involved the administration of the "speeded" sublexical frequency task with the single, bigram, or trigram conditions administered in the same order of presentation as session 1. The Auditory Analysis Task, and the Word- Identification subtest were also administered during session 2. Other measures unrelated to the present dissertation were also administered during this session.

Results and Discussion

General Overview

The first set of analyses examines performance on the computer-based sublexical frequency task in an attempt to identify at what age children begin to show signs of orthographic sensitivity. The two remaining measures of orthographic awareness, letter-cluster and word likeness, were also examined in order to address the same question with commonly-used, albeit criticized measures. Follow-up multiple regression analyses are then presented to determine the independent contribution of phonological skill and naming speed measures to orthographic sensitivity. Finally, multiple regression analyses have been used to determine the independent contribution of phonological, orthographic, and naming speed measures to word recognition skill.

Sublexical Frequency Task

Concerning the sublexical frequency task, the response time (RT) findings are presented first and considered of primary importance due to their theoretical relevance to orthographic frequency effects expected to be found among developing readers. Shorter reaction times to identify high versus low frequency letter strings are thought to index a person's overall sensitivity to orthographic information; lexical decision tasks and word frequency effects typically focus on RT information. Findings based upon error data are also presented, however, as a means to confirm the meaningfulness of the RT results (e.g., to examine the presence or absence of speed-accuracy tradeoffs).

To ensure that the data was in suitable form for parametric analyses, a recursive outlier analysis was conducted on the response time (RT) data for the single letter, bigram, and trigram stimuli for each individual. An outlier rejection criterion of 3 standard deviations from the participants own mean was used. Furthermore, each child's speed of responding accurately to single letter, bigram, and trigram stimuli was converted to logs which reduced the positive skewness apparent in the distribution of the latency responses. (Overall findings did not differ, however, when identical analyses were conducted with non-transformed data). Finally, all RT analyses were based upon "yes" trials only, that is, trials in which the target letter was found within the subsequently seen display. As this task required a direct match between display and target, response times for "yes" trials seemed interpretable. However, analyses of correct "no" condition responses were not pursued, because their interpretation was less certain. That is, a "no" response may involve a greater number of mental operations than a "yes" response and children may vary in the number of operations employed.

Grade Differences in Response Time as a Function of Display Size, Stimulus Frequency, and Display Rate

Log transformed response time data were initially analyzed using a mixed-model multivariate analysis of variance (MANOVA) in which there was one between-groups factor of grade (grade 1,2,and 3), and three within-groups factors consisting of display size (single letter, bigram, and trigram), stimulus frequency (high and low), and display rate (speeded and unspeeded). This first analysis was undertaken to determine whether the two display rates, speeded and unspeeded, should be considered separately. Response time results revealed a significant four-way (grade by display size by frequency by display rate) interaction, $F(4,162)=3.0$, $p<.05$. (Please refer to Appendix E for the source tables that correspond sequentially to the present MANOVA analyses.)

Follow-up analyses of the within-subject factors for each grade level were performed to identify the specific effects of display rate contained in this interaction. Results revealed a significant three-way (display size by frequency by display rate) interaction $F(2,26)=4.02$, $p<.05$ among grade 1 children. Grade 3 children responded significantly faster on speeded trials compared to unspeeded ones as indicated by a main effect of display rate $F(1,27)=5.33$, $p<.05$, with no higher-order interactions emerging among these children. In short, display rate findings among the grade 1 and 3 students suggest the necessity to consider speeded and unspeeded conditions separately.

Additional support for the differential impact of display rate was found in a MANOVA analysis using error data. Error data were calculated to represent the percent error within the "yes" trials for either the single letter, bigram, or trigram conditions. Based upon the total sample MANOVA, results indicated a main effect for display rate ($F(1,81)=21.13$, $p<.001$), indicating that across the entire sample, more errors were committed on speeded versus unspeeded trials. Furthermore, a display rate by display size interaction was revealed, $F(2,80)=3.90$, $p<.05$, as well as a display rate by frequency interaction $F(1,81)=9.57$, $p<.01$. These accuracy differences resulting from the two display rates adds further support to the conclusion that speeded and unspeeded conditions must be considered separately.

A closer inspection of speeded findings revealed the presence of speed-accuracy tradeoffs. As mentioned above, grade 3 children responded significantly faster on speeded trials compared to unspeeded ones but had significantly more errors on the speeded than the unspeeded trials as revealed by the main effect of display rate on accuracy F(1,27)=7.87, p<.01. It is possible that the "speeded" quality of these trials heightened the responsiveness and "energy level" of children, encouraging them to respond more quickly, and possibly contributing to their greater number of errors. To enhance the interpretability of the findings, all subsequent MANOVAS were conducted using unspeeded trials to avoid the interpretive difficulties posed by the speed-accuracy tradeoff effects found among speeded conditions. While subsequent analyses were based upon unspeeded trials alone, results for speeded trials are presented in Appendix F.

Grade Differences in Response Time as a Function of Display Size and Stimulus Frequency

A mixed-model MANOVA was subsequently conducted on the log transformed RT data based upon unspeeded trials only. Thus, there was one between-groups factor of grade (grades 1,2,and 3), and two within-groups factors consisting of display size (single letter, bigram, and trigram), and stimulus frequency (high and low). The analysis revealed a significant main effect of grade F(2,81)=27.1, p<.001, with response time decreasing as grade level increased. Response times also increased with increases in display size across the total sample F(2,80)=79.4, p<.001. Finally, a significant grade by frequency interaction for response time was also found, F(2,81)=3.3, p<.05. No significant higher order interactions were found.

Separate MANOVAS were subsequently carried out for each individual grade in order to clarify the significant grade by frequency interaction. The only significant effects of frequency among the different grades were found in grade 3. Specifically, a main effect was identified for frequency F(1,27)=12.51, p=.001 with high frequency items being responded to significantly more quickly than low frequency items. Specifically, mean (standard deviation) response times for high frequency items were 906.41 (163.72) msec. versus 951.96 (181.78) msec. for the low frequency stimuli. Thus, within the present sample, it is not until grade 3 that children begin to demonstrate a sensitivity to orthographic redundancy as seen in their response advantage for high frequency versus low frequency display items.

Consistent with a lack of interaction of grade with display size, significant and comparable main effects were found for the impact of display size on RT in grade 1 children F(2,26)=20.1, p<.001, grade 2 F(2,26)=35.5, p<.001, and grade 3 F(2,26)=37.0, p<.001. Examination of mean response times and standard deviations for each grade across display size, presented in Table 1, reveals that within each grade, response times increased with an increase in display size from single letter to bigram to trigram. This finding was significant for all conditions except among grade 1 students where bigram and trigram response times did not differ statistically from each other. This latter result was confirmed by paired t-test analyses. Simple effects were tested to assess the prediction that the oldest children would show letter cluster unitization by their ability to process trigrams as quickly as bigrams. Contrary to this prediction, the results revealed that the oldest children took longer to process trigrams than bigrams.

Table 1

Means and Standard Deviations (in ms) of Display Size by Grade

	Single	Bigram	Trigram
Gr. 1	1194.23 (439.43)	1465.90 (376.20)	1594.15 (401.28)
Gr. 2	863.01 (252.07)	1087.72 (321.91)	1191.10 (301.57)
Gr. 3	796.65 (154.08)	953.55 (197.43)	1037.36 (229.98)

Grade Differences in Accuracy as a Function of Display Size and Stimulus Frequency

A mixed-model MANOVA similar to the one described for the RT data was conducted for the error data, based on "yes" trials only, in order to assess the interpretability of the response time findings described above. Thus, there was one between-groups factor of grade (grade 1,2,and 3), and two within-groups factors consisting of display size (single letter, bigram, and trigram), and stimulus frequency (high and low). The analysis revealed a significant main effect of grade F(2,81)=4.1, p<.05. Examination of mean errors and standard deviations, presented in Table 2, reveals that grade 1 students made significantly more errors than grade 2 and 3 students. Grade 2 and 3 students did not differ. These findings were confirmed by a Student Newman-Keuls error analysis of the grade factor.

Table 2

Means and Standard Deviations of Percent Error by Grade

Grade 1	Grade 2	Grade 3
8.60 (5.67)	5.13 (4.46)	5.51 (4.71)

Results also revealed a trend for error rates to increase with increases in display size when analyzing the total sample F(2,80)=3.0, $p<.06$. No other main effects or higher order interactions were significant. These findings are consistent with prior expectations and are not suggestive of any speed-accuracy tradeoff effects. Specifically, the absence of any frequency effects in grade 3 concerning the error analyses suggests that the frequency effect found among grade 3 students in the RT data may be meaningfully interpreted. Furthermore, the overall low error rates found among the grade 1, 2, and 3 children adds further support towards the appropriateness for interpreting the RT results. Specifically, grade 1 mean error rates range from 3.6 to 13.5 percent error depending on display size and frequency condition. Grade 2 mean error rates range from 3.0 to 6.9 percent, and mean error rates within grade 3 range from 4.3 to 6.8 percent.

In short, the present error analysis supports the interpretability of the RT data findings which reveal that it is not until grade 3 that children in the present sample demonstrated a sensitivity to orthographic redundancy as seen in their faster response times for high frequency versus low frequency display items.

Grade 3 Frequency Effect and its Relationship to Single Word Identification

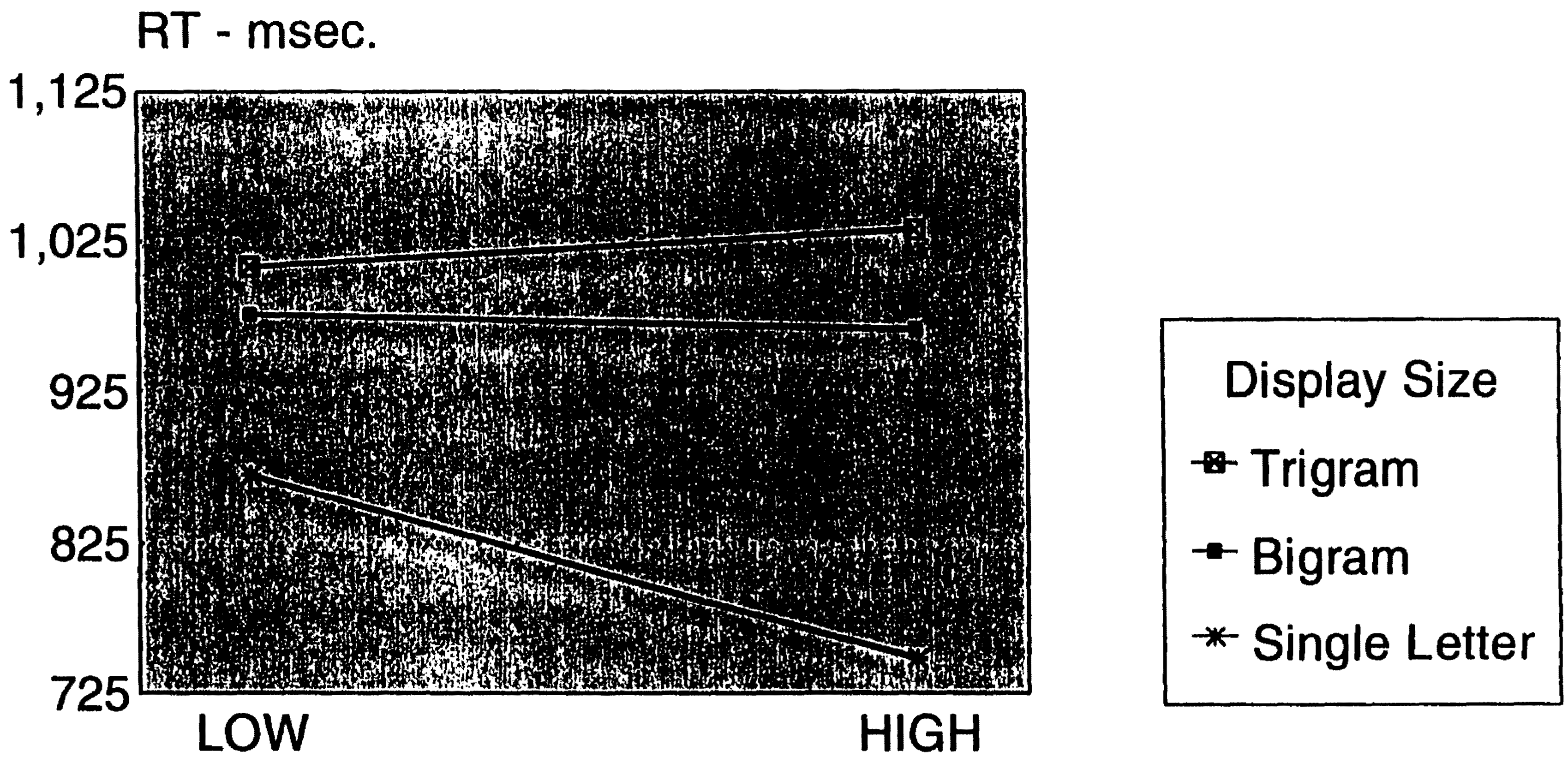
In order to examine the relationship between the frequency effect identified in grade 3 and single word identification, the grade 3 sample was divided into more skilled and less skilled readers along the median scaled score on the Woodcock-Johnson-R Letter Word Identification subtest (LWID). A MANOVA was carried out on the log transformed RT data in which there was one between-group factor of reader group (more skilled/less skilled), and two within-group factors consisting of display size (single letter, bigram, and trigram), and stimulus frequency (high/low). The analysis revealed a significant main effect of display size $F(2,25)=35.9$, $p<.001$, with response time increasing as display sizes became larger. A main effect of frequency was also identified $F(1,26)=12.06$, $p<.01$, with high frequency items being responded to more quickly than low frequency stimuli. Finally, a significant reader group by display size by frequency interaction was also found, $F(2,25)=3.4$, $p<.05$. Examination of accuracy data confirmed that no speed accuracy trade-off effects were present. Separate MANOVAS were subsequently carried out for each reader group (more skilled/less skilled) in order to clarify the significant reader group by display size by frequency interaction.

Response time (log transformed) MANOVA results for the less skilled readers revealed a main effect of display size $F(2,12)=32.3$, $p<.001$, a trend for frequency $F(1,13)=4.13$, $p<.07$, as well as a trend for a display size by frequency interaction $F(2,12)=3.3$, $p<.08$. To illustrate this interaction, mean response times for each of the display sizes at each frequency are presented in Figure 1. As is apparent in Figure 1, response times for high and low frequency bigrams and trigrams did not differ, although high frequency single letters were responded to significantly more quickly than low frequency single letters. These impressions were confirmed by paired t-test analyses.

The response time advantage for high frequency single letters compared to low frequency items, among the less skilled readers, was an unexpected result as it was thought these readers might demonstrate a complete lack of sensitivity to frequency regardless of display size. Although not evident for the single letter condition, the lack of a frequency effect among the less skilled readers for bigrams and trigrams supports the initial prediction that such readers do demonstrate an insensitivity to letter cluster frequency, or more generally, orthographic redundancy. It is also possible that these childrens' insensitivity to such orthographic information might have contributed to their relative lack of proficiency at single word identification.

In contrast to the less skilled reader findings, MANOVA results of the log transformed RT data of more skilled readers revealed main effects of display size $F(2,12)=14.1$, $p<.01$ and frequency $F(1,13)=10.0$, $p<.01$. A significant display size by frequency interaction was not identified. The main effect for display size indicated that response times increased with the increase in display sizes. Concerning frequency, high frequency items were responded to more quickly than low frequency items. Specifically, the mean and standard deviation for the high frequency items was 897.02 (141.91) msec. compared to 952.49 (171.51) msec. for the low frequency items. Please refer to Figure 2 for an illustration of these findings.

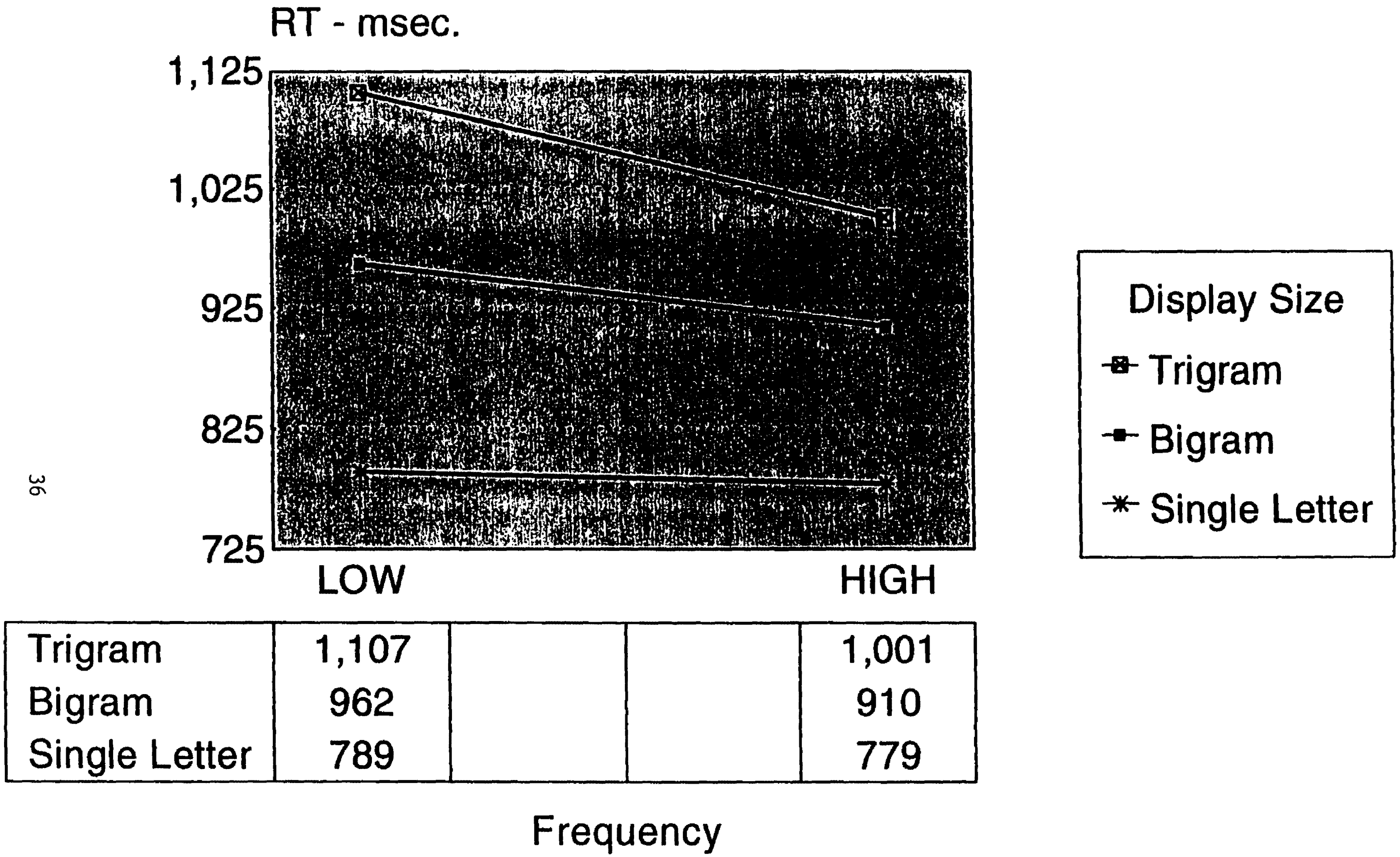
The presence of an overall frequency effect among the relatively skilled readers is consistent with the initial prediction that only the better readers would demonstrate a



Trigram	1,008			1,033
Bigram	976			966
Single Letter	870			748

Frequency

Figure 1. Response times among less skilled grade 3 readers as a function of frequency (low/high) and display size (single, bigram, trigram).



	LOW			HIGH
Trigram	1,107			1,001
Bigram	962			910
Single Letter	789			779

Figure 2. Response times among more skilled grade 3 readers as a function of frequency (low/high) and display size (single, bigram, trigram).

sensitivity to letter cluster frequency, or more generally, to orthographic redundancy. These findings also suggest that the sensitivity of the more skilled readers to the frequency of letter clusters (bigrams and trigrams) might have contributed to their relative proficiency at single word identification, thus linking the overall grade 3 frequency effect to word identifications skills. Finally, the analysis of accuracy data for the less skilled and more skilled readers revealed the absence of significant accuracy effects due to frequency. Speed accuracy trade-off effects are therefore unlikely to account for findings.

Multiple Regression Analyses

As a follow-up to the present MANOVA findings, multiple regression analyses were carried out to address the following questions: First, "what skills contribute uniquely to the frequency effect found in grade 3, and second, "what skills contribute uniquely to single word identification?". A third question asks what skills contribute to the other indices of orthographic awareness, letter-cluster and word likeness, and how these variables and others relate to word identification.

Before proceeding to describe these results, an introductory summary is required. First, results from the MANOVA analyses found that frequency effects in grade 3 were linked to proficiency in single word identification. One way to form a metric describing this frequency effect is to construct a response time difference score between high frequency and low frequency items, viz., high frequency bigram RTs subtracted from low frequency bigram RTs and high frequency trigram RTs subtracted from low frequency trigram RTs. The sum of these two frequency differences will subsequently be referred to as the frequency difference (FRQDIFF) score. Single letters were not included in this calculation as their general purpose was to provide a baseline measure from which to compare bigram and trigram response times rather than an insight into the development of sublexical frequency effects per se.

As presented in Table 3, an examination of the correlations between FRQDIFF and more traditional measures of orthographic awareness, letter-cluster ($r=.52$, $p<.01$) and word likeness ($r=.37$, $p<.06$), reveals that FRQDIFF may be considered a measure of orthographic awareness. Letter-cluster and word likeness are correlated .39, $p<.05$. Finally, as anticipated by the MANOVA findings of frequency effects and reader group status, a significant correlation of .42, $p<.05$ exists between FRQDIFF and single word identification (WID) among grade 3 students alone. Since significant frequency effects did not occur prior to grade 3, no significant relationship between FRQDIFF and single word identification was expected in grades 1 and 2. Indeed, the correlation of FRQDIFF and WID, in grades 1 and 2 was not significant, $p > .10$.

Table 3

Intercorrelations between Single Word Identification and Individual Difference Variables in Grade 3

	FRQDIFF	CLUSTER	WORD LIKENESS	RAN-L	AAT	WID
FRQDIFF	1.00					
CLUSTER	.52**	1.00				
WORDLIKE	.37+	.39*	1.00			
RAN-L	.23	.29	.37+	1.00		
AAT	.52**	.60**	.47*	.44*	1.00	
WID	.42*	.50**	.46*	.58**	.65**	1.00

+ $p < .10$ * $p < .05$ ** $p < .01$

Skills Contributing to the Frequency Effect

Given this background, I now return to the first question addressed by the multiple regression analyses. What skills contribute uniquely to the grade 3 frequency effect found in the present study? In this analysis, the unique contributions to the frequency effect of letter naming speed (RAN-Letter) and phonological awareness (AAT) were assessed by examining their respective partial correlations with the dependent variable while controlling for the remaining independent variable in the equation. Results indicated that of these two measures only phonological awareness skill (T=2.75, p=.011) contributed uniquely to grade 3 children's FRQDIFF, the frequency effect. This finding does not support the initial prediction which stated that in addition to phonological awareness, rapid naming speed would also offer unique variance to orthographic skill. However, the strong contribution of phonological awareness skill to FRQDIFF is consistent with Ehri's (1992) theoretical position identifying a direct relationship between children's phonological processing skill and the subsequent development of orthographic abilities.

Skills Contributing to Single Word Identification

I turn next to the second question addressed by the multiple regression analyses, i.e., within the grade 3 sample, what various skills relate uniquely to single word identification? In this analysis, orthographic awareness, letter naming speed, and phonological awareness, as measured respectively by FRQDIFF, RAN-Letter and AAT, were analyzed to test their unique contribution to the prediction of single word identification. As assessed in the manner described in the previous analysis, only AAT T=2.41, p=.024, and RAN-Letter T=2.36, p=.027 contributed uniquely to single word identification. Upon examination of Table 3, it appears that while FRQDIFF and single word identification are significantly correlated (r=.42), the higher degree of overlap between FRQDIFF and AAT was responsible for the lack of unique contribution of FRQDIFF to word identification as had been predicted.

Grade Differences in Orthographic Sensitivity as measured by the Word Likeness and Letter-Cluster Tasks.

It was not until grade 3 that children in the present sample demonstrated orthographic sensitivity on the RT frequency task, as seen in their response time advantage for high frequency versus low frequency display items. The following analyses were undertaken to determine at what grade would evidence emerge for orthographic sensitivity on two alternate measures of orthographic awareness, specifically, the word likeness and letter-cluster tasks.

An accuracy measure (percent correct) was used for each task. For both tasks, 50 percent accurate represented chance performance. Furthermore, for the letter-cluster task, only data from "yes" conditions were analyzed for the same reason that only "yes" analyses were conducted for the RT frequency task [i.e., "yes" responses require a single match between the display cluster and the preceding whole word]. In contrast, "no" responses inherently require a greater number of mental operations, thus decreasing their overall interpretability.

Examination of means and standard deviations for percent correct on the word likeness and letter-cluster tasks, as presented in Table 4, reveals that grade 1 accuracy on both of these orthographic tasks was considerably lower than the accuracy achieved by grade 2 or 3 students. A Student Newman-Keuls analysis of grade confirmed that first-grade performance differed from second and third grade levels for both measures of orthographic awareness, $p<.01$. Furthermore, grade 2 and 3 performances did not differ from each other on both tasks.

Table 4.

Means and Standard Deviations of Percent Correct as a Function of Grade and Orthographic Task

Grade	Word likeness		Letter-Cluster	
	Mean	SD	Mean	SD
First	66.85	15.26	63.32	21.08
Second	83.57	14.90	82.19	13.05
Third	87.68	13.84	88.44	9.47

Based upon these grade differences, two sets of multiple regression analyses were conducted to find predictors of word likeness and letter-cluster data. The first set was designed to determine the specific skills associated with proficient orthographic skill by combining grade 2 and 3 data. In contrast, the second set was to examine the skills associated with just emerging orthographic skill as evident among grade 1 children.

Table 5

Intercorrelations between Single Word Identification and Individual Difference Variables in Grades 2 and 3 combined.

	CLUSTER	WORDLIKE	RAN-L	AAT	WID
CLUSTER	1.00				
WORDLIKE	.47**	1.00			
RAN-L	.47**	.53**	1.00		
AAT	.46**	.44**	.47**	1.00	
WID	.52**	.57**	.58**	.63**	1.00

* p < .05 ** p < .01

Skills Contributing to Proficient Orthographic Skill as measured by Letter-Cluster and Word Likeness Tasks

Table 5 reports the intercorrelation of measures in grade 2 and 3 children. The unique contributions of grade, phonological awareness, and letter naming speed were examined with regards to their prediction of letter-cluster performance in grades 2 and 3. Results indicated that grade level (T=2.97, p=.0049), AAT (T=2.07, p=.0441), and RAN-Letter (T=2.15, p=.0369) all contributed uniquely to letter-cluster performance among these children. This finding is supportive of the initial prediction that rapid naming speed, in addition to phonological awareness skill, would offer unique variance to orthographic skill. This finding replicates Golden and Bowers (1993) which used the same letter-cluster task in grades 1, 2, and 3.

The word likeness task was then analyzed in the same manner as the letter-cluster task above. Specifically, the unique contributions of grade, phonological awareness, and letter naming speed were examined with regards to their prediction to word likeness performance. Interestingly, results indicated that only RAN-Letter (T=3.07, p=.0037) contributed uniquely to word likeness performance among children in grades 2 and 3.

Skills Contributing to Just Emerging Orthographic Skill.

The unique contributions of phonological awareness and letter naming speed to predictions of letter-cluster and word likeness performance among grade 1 students were also examined. Results indicated a trend towards a unique contribution of AAT (T=2.00, p=.0570) to emerging letter-cluster proficiency. Concerning word likeness performance, AAT was again found to contribute uniquely to this skill (T=2.13, p=.0444) in the first grade sample. Finally, letter naming speed was found to be unrelated to the emerging orthographic skill in both grade 1 letter-cluster and word likeness performances. Table 6 provides the intercorrelations of rapid naming speed (RAN-L), and AAT to the just emerging letter-cluster, and word likeness skill among grade 1 children. Table 7 provides this same information for grade 2 children who, as a group, demonstrate proficiency with these two orthographic tasks. Note that while AAT alone is related to emerging letter-cluster and word likeness skill in grade 1, both AAT and RAN-L are related to these orthographic tasks once proficiency is first observed in grade 2.

Table 6

Intercorrelations between Individual Difference Variables in Grades 1

	CLUSTER	WORDLIKE	RAN-L	AAT
CLUSTER	1.00			
WORDLIKE	.37	1.00		
RAN-L	.38	.28	1.00	
AAT	.52**	.50**	.65**	1.00

* p < .05 ** p < .01

Table 7

Intercorrelations between Individual Difference Variables in Grades 2.

	CLUSTER	WORDLIKE	RAN-L	AAT
CLUSTER	1.00			
WORDLIKE	.51**	1.00		
RAN-L	.59**	.67**	1.00	
AAT	.47*	.46*	.52**	1.00

* p < .05 ** p < .01

Skills Contributing to Single Word Identification

In this final set of analyses, the unique contributions of grade, phonological awareness, letter naming speed, and orthographic awareness, were examined with regards to their ability to predict uniquely to single word identification. For these analyses, orthographic awareness was measured by both the letter-cluster and the word likeness task, and entered as alternatives in the analyses. Data from only grades 2 and 3 were combined due to the high degree of orthographic proficiency exhibited by these two grade levels in letter-cluster and word likeness performance. Results involving letter-cluster data revealed that grade (T=2.94, p=.005), AAT (T=3.22, p=.0022), letter-cluster (T=2.10, p=.0409), and RAN-Letter (T=4.05, p=.0002) all contributed uniquely to single word identification. The same analysis using word likeness data instead of letter-cluster data revealed identical results in that grade (T=3.71, p=.0005), AAT (T=3.78, p=.0005), word likeness (T=3.63, p=.0007), and RAN-Letter (T=3.28, p=.0019) also contributed uniquely to single word identification. In short, contrary to the initial prediction, rapid naming speed in addition to phonological and orthographic skill contributed uniquely to single word identification in the older (grade 2 and grade 3) children.

General Discussion

To summarize, present results confirm earlier findings that sometime between the second and fourth grade children seem to exhibit a sensitivity to orthographic structure (e.g., Golinkoff, 1974; Henderson & Chard, 1980; Rosinski & Wheeler, 1972). In the current study, grade 2 and 3 children demonstrated significant mastery on the word likeness and letter cluster-tasks, while grade 3 children alone displayed an awareness of orthographic structure as demonstrated by their significant RT advantage for high versus low frequency sublexical stimuli. Based upon the findings of Adams (1981, 1990) and Seidenberg and McClelland (1989), quick response times to high frequency items may be considered to arise from the facilitory activation of letters that have previously been seen together. Conversely, the relatively slower response times among low frequency items may be thought to arise from the inhibitory effect due to the rareness of co-occurrence among these letter patterns. It is likely these two processes, one facilitory and one inhibitory, together account for the observed differences between high and low frequency stimuli. Finally, the fact that only the more skilled grade 3 readers demonstrated this frequency effect suggests that perhaps it is their sensitivity to orthography which helps contribute to their overall success at single word identification.

What Skills Contribute Uniquely to Orthographic Sensitivity?

Having identified the existence of orthographic sensitivity among grade 2 and 3 students, the following question arises, "what skills contribute uniquely to the orthographic sensitivity measured by the study's three orthographic tasks?". The multiple regression analysis predicting to the RT frequency data reveals that only phonological awareness skill contributes uniquely to the sublexical frequency effect found in grade 3. This finding is inconsistent with the initial prediction which stated that in addition to phonological awareness, rapid naming speed would also offer unique variance to orthographic skill. The relatively low correlation between rapid naming speed and the FRQDIFF (r=.23, p=.24) is an unexpected finding as it was hypothesized that rapid and efficient access to letter codes was an integral ingredient of the development of orthographic sensitivity. However, the strong contribution of phonological awareness skill to sublexical frequency effects is consistent with Ehri's (1992) theoretical position identifying the direct relationship between a child's phonological processing skill and the subsequent development of orthographic abilities.

In contrast to findings based upon the sublexical frequency task, support for the original hypothesis exists when the letter-cluster measure is used. The multiple regression analysis using letter-cluster performance demonstrated that phonological awareness skill and letter naming speed both contribute uniquely to letter-cluster performance. This finding also replicates the Golden and Bowers (1993) result which identified the same unique contributions of rapid naming speed and phonological processing skill to letter-cluster performance.

Although word likeness findings revealed that only rapid naming speed contributed uniquely to performance on this orthographic measure, the high correlation of AAT and RAN-L to word likeness performance, .44 (p<.01) and .53 (p<.01), respectively, suggests that both phonological skill and rapid naming speed are related to orthographic performance as initially predicted. It is the high degree of overlap between AAT and RAN-L's contribution to the task that seems responsible for eliminating AAT's expected unique contribution to word likeness performance (see Table 5). Thus, overall findings suggest that both phonological awareness skill and rapid naming speed are related to proficiency on the word likeness and letter-cluster tasks. Furthermore, these latter results provide support for the underlying hypothesis that in addition to phonological processing skill, rapid and efficient access to letter codes may also be meaningfully related to the development of effective orthographic processing as predicted by Adams's model of orthographic redundancy.

Why does phonological awareness skill alone contribute uniquely to the sublexical frequency effect, whereas, phonological skill and rapid naming speed are both related to letter-cluster and word likeness performance? In considering this difference it should be noted that the orthographic skill required to master the letter-cluster and word likeness task is strongly evident by grade 2, whereas, initial evidence for sublexical frequency effects does not begin to emerge until grade 3. This suggests that the frequency task may be more challenging than the letter-cluster or word likeness measures and consequently does not reveal similar levels of mastery until later in the child's development. Given this observation, closer inspection of the correlations involving letter-cluster and word likeness, as presented in Table 6, reveals that as these orthographic skills are just beginning to emerge in grade 1, only phonological skill is significantly correlated with each of them, $r=.52$, $p<.01$ for letter-cluster, and $r=.50$, $p<.01$ for word likeness. However, as illustrated in Table 7, rapid naming speed in addition to phonological skill is significantly correlated with mastery levels on both measures of orthography by grade 2. Specifically, in grade 2, AAT and RAN-L are both correlated with letter-cluster performance ($r=.47$, $p<.05$ and $r=.59$, $p<.01$, respectively). The same findings are also evident concerning word likeness. For example, AAT and RAN-L are both correlated with word likeness ($r=.46$, $p<.05$ and $.67$, $p<.01$, respectively). In short, based upon letter-cluster and word likeness data, it appears that phonological skill alone is related to the just emerging orthographic skill in grade 1. However, rapid naming speed in addition to phonological processing appear related to the proficiency in orthographic ability that follows developmentally in grade 2. Based upon these observations, it is speculated that the same pattern may appear in the FRQDIFF data. Specifically, it is suggested that while AAT alone is related to the just emerging frequency effect in grade 3, letter naming speed in addition to phonological awareness skill may contribute uniquely to the proficient frequency task performance expected to occur in later grades. Thus, phonological skill alone is thought to be related to the earliest emergence of orthographic sensitivity, whereas letter naming speed, in addition to phonological awareness, is believed to be related once proficient levels of orthographic mastery have emerged for some children.

Why is phonological awareness skill alone related to emerging orthographic abilities, whereas both phonological skill and rapid naming speed are related to orthographic capabilities that are well established? I believe an answer to this question may be found in a re-examination of the Ehri (1992) model of word recognition. To review briefly, Ehri suggests that the initial route to word recognition involves the phonological decoding of individual letters whereby letter-sound correspondences are used to decipher the word's pronunciation. In the second stage, after a word has been phonologically decoded several times in stage 1, a direct visual-phonological connection is formed between the word's spelling and its pronunciation. Once this connection is established, it is thought that children subsequently refer directly to the spelling/pronunciation link rather than to phonological recoding. I believe that Ehri's first stage of the model can provide a rationale for the initial finding that phonological awareness skill alone is related to emerging orthographic abilities. If a child's earliest strategy to decipher text lies in the attempt to decode phonologically, then it is reasonable to assume that early signs of common letter pattern recognition, a skill closely related to early word recognition, would also rely heavily on such phonological skills. Concerning the result that phonological skill and rapid naming speed are both related to proficient levels of orthographic awareness, I again refer to Ehri's model. When Ehri states that once a word has been phonologically decoded several times, a direct visual-phonological connection is formed between the word's spelling and its pronunciation, it seems reasonable to add that letter fluency could contribute to the child's ability to take full advantage of the repeated decodings by allowing the child to process the textual material thoroughly and quickly enough to allow the amalgamation of spelling-pronunciation connections. This rationale permits an understanding of the fact that phonological skill and rapid naming speed are both related to established levels of orthographic mastery.

Differences among Orthographic Measures

The fact that each of the three orthographic measures used in the present sample revealed slightly different combinations of associated skills shows the importance of recognizing that distinct measures of orthographic awareness are likely to assess this skill in unique ways. This observation should be considered carefully when deciding which specific measure of orthography to use in future research. The fact that various orthographic measures seem to have different levels of difficulty has also been shown to affect results and should be carefully considered in future research.

Given that each of the three measures of orthographic awareness identified slightly different associated skills, it seems reasonable to speculate about the differences in task demands which may be related differentially to various cognitive skills. First, concerning the word likeness task, children were asked to circle the letter string that appeared more word like (e.g. ramine versus miema). It appears that success on this task could benefit not only from a crude awareness of orthographic redundancy, but also from phonological decoding skills that could recognize how much easier it is to pronounce "ramine".

Given that the letter-cluster measure begins with the presentation of a real word, it is not surprising this task would be associated with word recognition skills. Indeed, a high correlation obtained between this orthographic task and word identification ($r=.60$, $p<.01$) supports this speculation (see Table 3). The letter-cluster task also appears to require the greatest memory resources of all three orthographic tasks given that children were required to "hold" the real word in memory before deciding whether the subsequent letter-cluster was contained in the real word or not.

Finally, the sublexical frequency task was developed in part to address some of the concerns pertaining to the letter-cluster task, i.e., memory load and readability. Memory load and spurious word recognition influences were reduced by starting each trial with the presentation of a single letter rather than an entire word. By reducing the word skill demand and relying heavily on the manipulation of letter pattern frequencies (low versus high), the sublexical frequency task may be a more independent measure of orthographic skill. It should be noted, however, that the sublexical frequency task may still implicate the phonological processor due to the differences in pronouncibility of high and low frequency stimuli.

It must also be noted that the general discrepancies between the three measures of orthographic awareness may also be due to the potential instability found among such correlational findings. It is possible that these findings could differ slightly given a new sample. Finally, although evidence has been presented to demonstrate that phonological skill and rapid naming speed are related to various measures of orthographic skill, the correlational nature of these findings does not allow causal conclusions. Furthermore, a third variable might also be responsible for these observed relationships.

What Skills Contribute Uniquely to Single Word Identification?

The final question addresses the various skills that relate uniquely to single word identification. While the sublexical frequency task was found to be significantly correlated ($r=.42$, $p<.05$) with single word reading, the multiple regression analysis incorporating this measure of orthography found that only phonological awareness and rapid naming speed skills contributed unique variance to single word identification, with variance contributed by sublexical frequency subsumed by AAT. In contrast, the same analysis strategy using either word likeness or letter-cluster data as alternate indices of orthographic functioning revealed that rapid naming speed accounts for unique variance in word identification in addition to the frequently observed finding that phonological and orthographic awareness skill also account for significant variation in identifying single words. In short, the present study identified the separate contribution of rapid naming speed in addition to the initially predicted contribution of phonological and orthographic skill, when the conventional orthographic measures were used.

In support of this last result, Manis and Doi (1995) report that among a sample of 80 children in grades 5 through 9, word naming speed (a measure usually highly related to symbol naming speed), lexical level orthographic skill, nonword decoding, and print exposure all provided relatively independent contributions to single word identification. They noted, however, that naming speed and orthographic skill overlapped considerably. This finding provides some support for the speculation that measures of rapid naming speed and sublexical frequency effects could overlap among an older sample of children.

These results demonstrate the need for continuing research to trace the development of different orthographic skills among children in grades 1 to 6. In addition to providing a greater understanding for the development of various orthographic skills, such research would also help identify the relationship between naming speed and orthographic awareness at varying levels of proficiency.

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APPENDIX A
ORTHOGRAPHIC AWARENESS MEASURES

SUBLEXICAL FREQUENCY TASK:

<u>SINGLE LETTER CONDITION:</u>
Practice Trials: (unspeeded and speeded conditions)

Index Cards:	Target Card	Display Card	Response
	a	h	No
	c	c	Yes
	g	g	Yes
	d	i	No
	y	b	No

Computer:	Target Letter	Display	Response
	a	t	No
	d	s	No
	y	y	Yes
	c	v	No
	w	w	Yes
	b	b	Yes

Single Letter Condition: <u>UNSPEEDED</u> - Experimental Stimuli

INSTRUCTIONS: Press the "yes" button if the first letter you see on the computer is the same as the second one you see. Press the "no" button if the first letter you see is NOT the same as the second one.

(*) = a positive match between target letter and display
(digit) = single letter frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY LETTERS

	Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1)	t (*)	u (2700)	t (8537)
2)	i (4493)	a (*)	a (7071)
3)	h (*)	l (3898)	h (6379)
4)	w (2505)	o (*)	o (5781)
5)	s (*)	h (6379)	s (5295)
6)	d (3770)	n (*)	n (5243)
7)	r (*)	t (8537)	r (5137)
8)	o (5781)	i (*)	i (4493)
9)	l (*)	r (5137)	l (3898)
10)	n (5243)	d (*)	d (3770)
11)	u (*)	s (5295)	u (2700)
12)	a (7071)	w (*)	w (2505)

Average Frequency - High = 5067

Single Letter Condition: UNSPEEDED - Experimental Stimuli

LOWER FREQUENCY LETTERS

13)	c (*)	y (1852)	c (2057)
14)	x (121)	g (*)	g (1903)
15)	y (*)	b (1418)	y (1852)
16)	z (54)	f (*)	f (1563)
17)	b (*)	j (131)	b (1418)
18)	v (863)	p (*)	p (1338)
19)	k (*)	q (66)	k (932)
20)	p (1338)	v (*)	v (863)
21)	j (*)	k (932)	j (131)
22)	g (1903)	x (*)	x (121)
23)	q (*)	c (2057)	q (66)
24)	f (1563)	z (*)	z (54)

Average Frequency - Low = 1025

Note: High frequency negative trials have higher frequency targets.
Low frequency negative trials have lower frequency targets.

Single Letter Condition: SPEEDED - Experimental Stimuli

(*) = a positive match between target letter and display
(digit) = single letter frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY LETTERS

	Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1)	t (*)	u (2700)	t (8537)
2)	w (2505)	a (*)	a (7071)
3)	h (*)	t (8537)	h (6379)
4)	i (4493)	o (*)	o (5781)
5)	s (*)	h (6379)	s (5295)
6)	a (7071)	n (*)	n (5243)
7)	r (*)	l (3898)	r (5137)
8)	d (3770)	i (*)	i (4493)
9)	l (*)	s (5295)	l (3898)
10)	n (5243)	d (*)	d (3770)
11)	u (*)	r (5137)	u (2700)
12)	o (5781)	w (*)	w (2505)

Average Frequency - High = 5067

Single Letter Condition: <u>SPEEDED</u> - Experimental Stimuli

LOWER FREQUENCY LETTERS

13)	c (*)	q (66)	c (2057)
14)	z (54)	g (*)	g (1903)
15)	y (*)	c (2057)	y (1852)
16)	v (163)	f (*)	f (1563)
17)	b (*)	y (1852)	b (1418)
18)	x (121)	p (*)	p (1338)
19)	k (*)	j (131)	k (932)
20)	g (1903)	v (*)	v (863)
21)	j (*)	b (1418)	j (131)
22)	p (1338)	x (*)	x (121)
23)	q (*)	k (932)	q (66)
24)	f (1563)	z (*)	z (54)

Average Frequency - Low = 1025

Note: High frequency negative trials have higher frequency targets.
Low frequency negative trials have lower frequency targets

<u>BIGRAM LETTER CONDITION:</u>

Practice Trials: (unspeeded and speeded conditions)

Index Cards:	Target Card	Display Card	Response
	d	jh	No
	a	ak	Yes
	z	tz	Yes
	n	ne	Yes
	h	op	No
Computer:	Target Letter	Display	
	a	af	Yes
	p	sv	No
	i	fi	Yes
	g	cg	Yes
	m	de	No
	f	ob	No

Bigram Letter Condition: <u>UNSPEEDED</u> - Experimental Stimuli

INSTRUCTIONS: Press the "yes" button if the first letter you see on the computer screen is one of the letters you see in the second group of letters. Press the "no" button if the first letter you see is NOT one of the letters you see in the second group.

(*) = a positive match between target letter and display
(digit) = summed bigram frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY BIGRAMS

	Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1)	e (*)	z	en (799)
2)	x	n (*)	nd (1213)
3)	m (*)	g	om (417)
4)	s	d (*)	ld (289)
5)	u (*)	k	ur (402)
6)	h	i (*)	ic (304)
7)	l (*)	t	ul (247)
8)	n	r (*)	ir (272)
9)	s (*)	h	st (754)
10)	j	v (*)	ve (683)
11)	h (*)	c	wh (472)
12)	s	e (*)	de (375)
13)	c (*)	y	ca (368)
14)	m	t (*)	te (583)
15)	o (*)	t	ro (504)
16)	b	a (*)	ta (259)

Frequency Average - High = 496

LOW FREQUENCY BIGRAMS

17)	c (*)	p	cs (7)
18)	v	t (*)	tz (1)
19)	b (*)	z	gb (1)
20)	t	c (*)	lc (6)
21)	t (*)	b	tj (0)
22)	l	k (*)	kb (0)
23)	n (*)	j	hn (0)
24)	u	g (*)	kg (0)
25)	g (*)	s	gp (0)
26)	f	y (*)	yd (0)
27)	k (*)	g	zk (1)
28)	c	f (*)	xf (1)
29)	d (*)	k	dm (1)
0)	i	t (*)	tg (2)
31)	s (*)	g	zs (3)
32)	s	f (*)	nf (5)

Frequency Average - Low = 1.8

Bigram Letter Condition: SPEEDED - Experimental Stimuli

(*) = a positive match between target letter and display
(digit) = summed bigram frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY BIGRAMS

	Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1)	a (*)	h	ar (802)
2)	k	i (*)	im (255)
3)	t (*)	r	ut (492)
4)	s	t (*)	nt (378)
5)	u (*)	l	un (278)
6)	b	n (*)	ng (771)
7)	t (*)	z	ot (415)
8)	w	g (*)	ig (233
9)	k (*)	u	ke (337)
10)	c	l (*)	li (390)
11)	a (*)	b	wa (595)
12)	q	e (*)	le (591)
13)	l (*)	u	la (332)
14)	o	s (*)	se (626)
15)	h (*)	e	sh (328)
16)	h	e (*)	re (1139)

Frequency Average - High = 498

LOW FREQUENCY BIGRAMS

17)	b (*)	s	bw (1)
18)	e	d (*)	dw (2)
19)	l (*)	a	xl (0)
20)	r	w (*)	pw (1)
21)	y (*)	k	yn (0)
22)	s	b (*)	bv (1)
23)	f (*)	h	gf (0)
24)	s	q (*)	nq (3)
25)	h (*)	f	hb (0)
26)	c	l (*)	lh (0)
27)	b (*)	f	wb (3)
28)	r	z (*)	tz (1)
29)	t (*)	z	tf (1)
30)	b	y (*)	yg (1)
31)	s (*)	p	fs (4)
32)	e	l (*)	zl (4)

Frequency Average - Low = 1.4

TRIGRAM LETTER CONDITION:

Practice Trials: (unspeeded and speeded conditions)

Index Cards:	Target Card	Display Card	Response
	t	taj	Yes
	k	enf	No
	b	irb	Yes
	d	sdk	Yes
	l	wpc	No

Computer:	Target Letter	Display	
	c	gtw	No
	b	bim	Yes
	l	jhy	No
	d	yuf	No
	s	kds	Yes
	r	erp	Yes

Trigram Letter Condition: UNSPEEDED - Experimental Stimuli

(*) = a positive match between target letter and display
(digit) = summed trigram frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY TRIGRAMS

	Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1)	r (*)	v	rom (130)
2)	m	s (*)	sta (101)
3)	i (*)	w	hin (109)
4)	h	a (*)	cal (66)
5)	a (*)	r	yea (75)
6)	d	s (*)	las (60)
7)	p (*)	z	ple (64)
8)	i	s (*)	som (69)
9)	n (*)	f	ong (95)
10)	r	l (*)	uld (143)
11)	t (*)	a	ost (89)
12)	o	t (*)	int (103)
13)	t (*)	b	ter (179)
14)	y	u (*)	ure (80)
15)	k (*)	l	ake (107)
16)	c	r (*)	ard (73)

Frequency Average - High = 96

Trigram Letter Condition: UNSPEEDED - Experimental Stimuli

LOW FREQUENCY TRIGRAMS

17) j (*)	s	rmj
18) k	f (*)	sdf
19) z (*)	l	znb
20) h	c (*)	ctg
21) b (*)	v	jbm
22) x	f (*)	lfp
23) v (*)	r	pkv
24) j	n (*)	sbn
25) d (*)	f	dlj
26) s	b (*)	bnr
27) t (*)	i	gtb
28) m	b (*)	fbv
29) k (*)	m	tgk
30) w	g (*)	jlg
31) k (*)	j	kpc
32) g	n (*)	nlr

Trigram Letter Condition: SPEEDED - Experimental Stimuli

(*) = a positive match between target letter and display
(digit) = summed trigram frequency (Mayzner & Tresselt, 1965)

HIGH FREQUENCY TRIGRAMS

Target Letter for Sequence #1	Target Letter for Sequence #2	Display/Freq
1) f (*)	m	fro (138)
2) c	w (*)	whi (125)
3) o (*)	y	mor (107)
4) d	e (*)	ven (77)
5) a (*)	b	lea (79)
6) k	s (*)	les (71)
7) s (*)	u	ste (65)
8) l	r (*)	res (65)
9) i (*)	z	ain (98)
10) r	s (*)	ast (91)
11) t (*)	i	ent (139)
12) d	t (*)	ust (96)
13) i (*)	n	ive (143)
14) j	a (*)	ame (91)
15) k (*)	t	ike (86)
16) w	r (*)	ort (67)

Frequency Average - High = 96

Trigram Letter Condition: SPEEDED - Experimental Stimuli

LOW FREQUENCY TRIGRAMS

17)	n (*)	j	fbn
18)	c	g (*)	wfg
19)	m (*)	p	mjs
20)	a	v (*)	vtp
21)	g (*)	y	lgk
22)	s	v (*)	bvf
23)	l (*)	d	sjl
24)	t	b (*)	rgb
25)	d (*)	m	dkt
26)	v	c (*)	cmj
27)	f (*)	h	gfj
28)	e	p (*)	jpm
29)	g (*)	t	kzg
30)	f	d (*)	kpd
31)	p (*)	f	pvk
32)	w	t (*)	tbj

LETTER-CLUSTER TASK (Berninger et al., 1991)

Instructions:

Look carefully at the word I show you. Then tell me whether the letters you see next had appeared in that word and are in exactly the same order as in the word. If those letters were in the word and in exactly that order, say "yes". If the letters were not in the word or were in the word in a different order, say "no".

Practice Trials:

water	te	(yes)
water	be	(no)
water	et	(no)

Experimental Stimuli:

yes response		no response	
must	st	must	sh
cats	ts	cats	st
nice	ce	nice	ne
well	el	well	il
with	th	with	sh
them	em	them	eh
than	an	than	at
been	ee	been	ea
head	he	head	re
good	oo	good	ol
once	on	once	ou
from	ro	from	or

yes resp.		no resp.	
what	wh	what	th
both	ot	both	at
running	nn	running	ny
quieter	ie	quieter	ei
careful	are	careful	rae
already	rea	already	ear
between	twe	between	wet
himself	sel	himself	sle
because	au	because	ua

Word Likeness Task
(Massaro et al., 1980; Rosinski & Wheeler, 1972)

Instructions:

Circle the group of letters that looks more like a real word.

Practice Trials:

REG-HIGH	IRREGULAR-LOW
A) swaner	rnwesa
B) bodule	obdeul
C) logren	egnrlo
D) trames	esrtma

Experimental Stimuli:

REG-HIGH	IRREG.-LOW	REG-HIGH	IRREG.-LOW
1) mauton	nmtaou	11) yulper	erplyu
2) blayer	rbleya	12) ramine	rniema
3) thaber	rtbeha	13) surtel	elsrtu
4) begrid	ebrgdi	14) pimsel	lsepmi
5) caleng	eclnga	15) snigel	nglesi
6) siflet	eflsti	16) sarted	dtsera
7) tasmer	emrtsa	17) vartle	tlerav
8) thomer	hretmo	18) sartil	irltsa
9) primet	rtpeim	19) drunet	edtrnu
10) rapley	epylra	20) triwen	rntewi

REG-HIGH - regular words - high frequency
IRREG.-LOW - irregular words - low frequency

APPENDIX B

PHONOLOGICAL AWARENESS MEASURE

AUDITORY ANALYSIS TEST (Rosner & Simon, 1971)

Now we're going to play a different word game. I'd like you to say cowboy. Now say it again but without boy. Say toothbrush. Say it again but without tooth.

E. If child makes an error on either practice item, correct and repeat instructions and practice items.

E. Write down incorrect responses. If child fails to give a response, repeat once. If child still fails to give a response, score 0 and continue.

Discontinue: 10 consecutive errors.

"Say birth(day) - now say it again but without the day ________

"Say car(pet) - now say it again but without the pet ________

bel(t) ________ (m)an ________ (b)lock ________

to(ne) ________ (s)our ________ stea(k) ________

(l)end ________ (s)mile ________ plea(se) ________

(g)ate ________ (c)lip ________ ti(me) ________

(sc)old ________ (b)reak ________ ro(de) ________

(w)ill ________ (t)rail ________ (sh)rug ________

g(l)ow ________ cr(e)ate ________ (st)rain ________

s(m)ell ________ de(s)k ________ st(r)eam ________

s(m)ack ________ s(k)in ________ s(w)ing ________

APPENDIX C

LETTER NAMING SPEED MEASURE

RAPID AUTOMATIZED NAMING (R.A.N.) - LETTERS

(Denckla & Rudel, 1976)

o	a	s	d	p	a	o	s	p	d
s	d	a	p	d	o	a	p	s	o
a	o	s	a	s	d	p	o	d	a
d	s	p	o	d	s	a	s	o	p
s	a	d	p	a	p	o	a	p	s

APPENDIX D

WORD RECOGNITION MEASURE

Woodcock-Johnson Psycho-Educational Battery-Revised: Word Identification Subtest

Test items:

1) X
2) B
3) R
4) C
5) N
6) k
7) Q
8) p
9) U
10) is
11) go
12) not
13) but
14) from
15) had
16) keep
17) said
18) got
19) their
20) light
21) once
22) use
23) young
24) point
25) piece
26) built
27) however
28) bachelor
29) social
30) knowledge
31) bought
32) investigate
33) thermostat
34) fierce
35) curious
36) authority
37) courageous
38) megaphone
39) illiteracy
40) acrylic
41) irregularities
42) silhouette
43) precipitate
44) reminiscent
45) chorused
46) debris
47) municipality
48) subsidiary
49) melodious
50) semiarid
52) facetious
53) satiate
54) puisne

APPENDIX E

MANOVA Summary Tables

Table E(1)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Grade, Display Rate, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	23.86	p<.001
Rate	(1,81)	2.53	NS
Grade X Rate	(2,81)	2.79	NS
Size	(2,80)	105.60	p<.001
Grade X Size	(4,162)	.34	NS
Freq	(1,81)	2.80	NS
Grade X Freq	(2,81)	1.64	NS
Rate X Size	(2,80)	2.16	NS
Grade X Rate X Size	(4,162)	.98	NS
Rate X Freq	(1,81)	.10	NS
Grade X Rate X Freq	(2,81)	1.00	NS
Size X Freq	(2,80)	1.92	NS
Grade X Size X Freq	(4,162)	.96	NS
Rate X Size X Freq	(2,80)	1.16	NS
Grade X Rate X Size X Freq	(4,162)	3.00	p<.05

Note: The Pillais multivariate test of significance was applied to all tests involving a within subject variable with more than two levels (Size) for all subsequent MANOVA analyses (Appendix E and F).

Table E(2)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Rate, Display Size, and Stimulus Frequency among Grade 1 students

	DF	F	Sig of F
Rate	(1,27)	1.90	NS
Size	(2,26)	32.79	p<.001
Freq	(1,27)	.15	NS
Rate X Size	(2,26)	1.49	NS
Rate X Freq	(1,27)	1.61	NS
Size X Freq	(2,26)	.14	NS
Rate X Size X Freq	(2,26)	4.02	p<.05

Table E(3)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Rate, Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Rate	(1,27)	5.33	p<.05
Size	(2,26)	32.13	p<.001
Freq	(1,27)	5.05	p<.05
Rate X Size	(2,26)	.75	NS
Rate X Freq	(1,27)	.15	NS
Size X Freq	(2,26)	.74	NS
Rate X Size X Freq	(2,26)	.94	NS

Table E(4)
MANOVA Summary Table for Percent Error data concerning differences in Grade, Display Rate, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	6.22	p<.01
Rate	(1,81)	21.13	p<.001
Grade X Rate	(2,81)	.20	NS
Size	(2,80)	15.30	p<.001
Grade X Size	(4,162)	3.43	p<.05
Freq	(1,81)	1.03	NS
Grade X Freq	(2,81)	.31	NS
Rate X Size	(2,80)	3.90	p<.05
Grade X Rate X Size	(4,162)	.58	NS
Rate X Freq	(1,81)	9.57	p<.01
Grade X Rate X Freq	(2,81)	.26	NS
Size X Freq	(2,80)	.83	NS
Grade X Size X Freq	(4,162)	2.98	p<.05
Rate X Size X Freq	(2,80)	.51	NS
Grade X Rate X Size X Freq	(4,162)	.27	NS

Table E(5)
MANOVA Summary Table for Percent Error data concerning differences in Display Rate, Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Rate	(1,27)	7.87	p<.01
Size	(2,26)	.38	NS
Freq	(1,27)	.21	NS
Rate X Size	(2,26)	.15	NS
Rate X Freq	(1,27)	1.62	NS
Size X Freq	(2,26)	2.33	NS
Rate X Size X Freq	(2,26)	.63	NS

Table E(6)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data (unspeeded condition only) concerning differences in Grade, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	27.10	p<.001
Size	(2,80)	79.42	p<.001
Grade X Size	(4,162)	.44	NS
Freq	(1,81)	1.24	NS
Grade X Freq	(2,81)	3.25	p<.05
Size X Freq	(2,80)	.95	NS
Grade X Size X Freq	(4,162)	1.52	NS

Table E(7)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data (unspeeded condition only) concerning differences in Display Size, and Stimulus Frequency among Grade 1 students

	DF	F	Sig of F
Size	(2,26)	20.01	p<.001
Freq	(1,27)	1.04	NS
Size X Freq	(2,26)	2.17	NS

Table E(8)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data (unspeeded condition only) concerning differences in Display Size, and Stimulus Frequency among Grade 2 students

	DF	F	Sig of F
Size	(2,26)	35.49	p<.001
Freq	(1,27)	2.32	NS
Size X Freq	(2,26)	.72	NS

Table E(9)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data (unspeeded condition only) concerning differences in Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Size	(2,26)	37.04	p<.001
Freq	(1,27)	12.51	p=.001
Size X Freq	(2,26)	.35	NS

Table E(10)
MANOVA Summary Table for Percent Error data (unspeeded condition only) concerning differences in Grade, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	4.10	p<.05
Size	(2,80)	2.98	p<.06
Grade X Size	(4,162)	1.66	NS
Freq	(1,81)	2.65	NS
Grade X Freq	(2,81)	.09	NS
Size X Freq	(2,80)	.99	NS
Grade X Size X Freq	(4,162)	1.12	NS

Table E(11)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Reader Group, Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Group	(1,26)	.01	NS
Size	(2,25)	35.93	p<.001
Group X Size	(2,25)	.43	NS
Freq	(1,26)	12.06	p<.01
Group X Freq	(2,26)	.02	NS
Size X Freq	(2,25)	.43	NS
Group X Size X Freq	(2,25)	3.41	p<.05

Table E(12)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Size, and Stimulus Frequency among Less Skilled Grade 3 readers

	DF	F	Sig of F
Size	(2,12)	32.28	p<.001
Freq	(1,13)	4.13	p<.07
Size X Freq	(2,12)	3.26	p<.08

Table E(13)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Size, and Stimulus Frequency among More Skilled Grade 3 readers

	DF	F	Sig of F
Size	(2,12)	14.08	p<.01
Freq	(1,13)	10.01	p<.01
Size X Freq	(2,12)	.65	NS

APPENDIX F

MANOVA Summary Tables: Speeded Condition only

Table F(1)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Grade, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	16.92	p<.001
Size	(2,80)	36.94	p<.001
Grade X Size	(4,162)	.84	NS
Freq	(1,81)	1.68	NS
Grade X Freq	(2,81)	.08	NS
Size X Freq	(2,80)	1.62	NS
Grade X Size X Freq	(4,162)	2.57	p<.05

Table F(2)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Size, and Stimulus Frequency among Grade 1 students

	DF	F	Sig of F
Size	(2,26)	6.57	p<.01
Freq	(1,27)	.35	NS
Size X Freq	(2,26)	2.36	NS

Table F(3)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Size, and Stimulus Frequency among Grade 2 students

	DF	F	Sig of F
Size	(2,26)	17.15	p<.001
Freq	(1,27)	.55	NS
Size X Freq	(2,26)	5.97	p<.01

Table F(4)
MANOVA Summary Table for Log Transformed Response Time (RT-LOG) data concerning differences in Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Size	(2,26)	15.64	p<.001
Freq	(1,27)	.79	NS
Size X Freq	(2,26)	1.03	NS

Table F(5)
MANOVA Summary Table for Percent Error data concerning differences in Grade, Display Size, and Stimulus Frequency

	DF	F	Sig of F
Grade	(2,81)	4.42	p<.05
Size	(2,80)	15.48	p<.001
Grade X Size	(4,162)	2.40	p<.06
Freq	(1,81)	8.00	p<.01
Grade X Freq	(2,81)	.45	NS
Size X Freq	(2,80)	.39	NS
Grade X Size X Freq	(4,162)	2.05	NS

Table F(6)
MANOVA Summary Table for Percent Error data concerning differences in Display Size, and Stimulus Frequency among Grade 1 students

	DF	F	Sig of F
Size	(2,26)	13.26	p<.001
Freq	(1,27)	4.92	p<.05
Size X Freq	(2,26)	3.00	NS

Table F(7)
MANOVA Summary Table for Percent Error data concerning differences in Display Size, and Stimulus Frequency among Grade 2 students

	DF	F	Sig of F
Size	(2,26)	8.13	p<.01
Freq	(1,27)	1.53	NS
Size X Freq	(2,26)	.17	NS

Table F(8)
MANOVA Summary Table for Percent Error data concerning differences in Display Size, and Stimulus Frequency among Grade 3 students

	DF	F	Sig of F
Size	(2,26)	.36	NS
Freq	(1,27)	2.04	NS
Size X Freq	(2,26)	1.59	NS

APPENDIX G

Table G(1)
Regression Analyses: Total R Square among Grade 3 students - (dependent variable: Frequency Difference Score - FRQDIFF)

Source of variance	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)

Total R Square = .27

Table G(2)
Regression Analyses: Total R Square among Grade 3 students - (dependent variable: Woodcock Word Identification)

Source of variance	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)
Frequency Difference Score	(FRQDIFF)

Total R Square = .54

Table G(3)
Regression Analyses: Total R Square among Grade 2 and 3 students combined - (dependent variable: Letter Cluster Task - CLUSTER)

Source of variance	
Grade	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)

Total R Square = .40

Table G(4)
Regression Analyses: Total R Square among Grade 2 and 3 students combined - (dependent variable: Word Likeness Task)

Source of variance	
Grade	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)

Total R Square = .39

Table G(5)
Regression Analyses: Total R Square among Grade 2 and 3 students combined - (dependent variable: Woodcock Word Identification)

Source of variance	
Grade	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)
Letter Cluster Task	(CLUSTER)

Total R Square = .67

Table G(6)
Regression Analyses: Total R Square among Grade 2 and 3 students combined - (dependent variable: Woodcock Word Identification)

Source of variance	
Grade	
Auditory Analysis Task	(AAT)
Letter Naming Speed	(RAN-L)
Word Likeness Task	(WORD LIKENESS)

Total R Square = .72

APPENDIX H

Raw Data: Definition of Variable Names.

RANL - Rapid Automatized Naming Test for Letters - letters/second
AAT - Auditory Analysis Task - # correct
CLUSTRBY - Letter-Cluster Task - Yes condition - # correct
WORDLIKE - Word Likeness Task - # correct
WIDSS - Woodcock Word-Identification Subtest - scaled score

USL - Unspeeded Single Low-Frequency stimuli - msec.
USH - Unspeeded Single High-Frequency stimuli - msec.
UBL - Unspeeded Bigram Low-Frequency stimuli - msec.
UBH - Unspeeded Bigram High-Frequency stimuli - msec.
UTL - Unspeeded Trigram Low-Frequency stimuli - msec.
UTH - Unspeeded Trigram High-Frequency stimuli - msec.

USL to UTH - YES Responses only

(.) or (99) designates missing data

See raw data found on pages 87 to 90.

```
14:23:26    University of Waterloo         DEC Alpha        OSF 1

GRADE     RANL AAT CLUSTRBY WORDLIKE WIDSS

  1       1.28  19      19       16    107
  1       1.22  22      13       16    113
  1       1.52  17      17       15    112
  1        .81  12      15       15    106
  1       1.32  16      12       19    110
  1       1.43  11      99       99    102
  1       1.79  21      19       17    123
  1       1.92  29      19       18    114
  1        .76   6      12       11    109
  1        .89  18      11       13     97
  1       1.22  10       4       13    109
  1        .93   1      15       10     72
  1        .96   4       5       14     87
  1        .     6      12       10     75
  1       1.25  19      11       12    114
  1       1.85  17      19       19    144
  1       1.19  18      12       12    114
  1       1.79  17      14        9    118
  1       1.85  26      16       11    129
  1       1.43  21      17       16    110
  1       1.22  26      16       16    121
  1        .65   2      10       13     79
  1       1.04   6       8        8     75
  1        .89   8      11       13     91
  1       1.72  14      13       10    106
  1        .93   6      20       12     73
  1       1.52   6       5       13     95
  1       1.09  11      14       10     85
  2       2.27   9      19       17     97
  2       2.17  27      19       20    134
  2       2.08  26      20       17    136
  2       2.00  29      20       20    139
  2       1.61  13      17       16    107
  2       1.61  16      15       18    111
  2       1.79  20      16       19    101
  2       1.72  23      21       16    130
  2       2.17  29      20       19    132
  2       1.47  24      15       16    116
  2       2.00  27      19       18     95
  2       1.56  24      16       13    122
  2        .     6      99       12     79
  2       1.85  29      17       18    114
  2       1.72  14      20       20    128
  2       2.50  29      20       20    138
  2       1.79  29      16       20    109
  2       1.52  25      18       15     95
  2       1.47  17      17       17     94
  2       1.72  21      18       18    109
  2       1.79  14      11       13     89
  2       1.52  14      13       16     98
  2       2.50  28      20       20    135
  2       1.32  16      11       16     96
  2       1.61  23      15       10     85
  2       1.14  22      17       11     83
  2       2.63  28      20       20    121
  2        .89   9      16       13     87
  3       2.00  11      16       17     86
  3       1.67  21      20        8    105
  3       1.72  16      16       15     89
  3       2.63  23      20       20    135
  3       1.79  17      15       15    108
```

```
GRADE     FAML AAT CLUSTRBY WORDLIKE WIDSS

  3       1.61  16      15       15     92
  3       1.92  20      19       19     98
  3       2.17  26      20       20    104
  3       1.43  14      19       18    105
  3       1.67  19      16       18    118
  3       1.92  17      19       17     96
  3       1.52  17      18       17     86
  3       1.67  17      19       15     99
  3       2.08  19      20       19    117
  3       1.35  23      16       19    105
  3       2.08  25      21       20    135
  3       2.08  16      16       14    103
  3       1.61  16      19       20     98
  3       1.79  21      18       15     93
  3       2.27  25      19       19    131
  3       2.78  29      21       20    129
  3       1.79  25      19       18    100
  3       1.35  28      21       20    110
  3       1.11  14      18       15     81
  3       2.08  23      21       18    103
  3       1.92  20      21       20    115
  3       2.00  29      21       20    122
  3       2.50  23      17       20    101

Number of cases read:  84    Number of cases listed:  84
```

GRADE	USL	USH	UBL	UBH	UTL	UTH
1	1225	929	1267	1378	1303	1386
1	1626	1987	2093	2800	1857	2121
1	1070	993	1249	1320	2982	1572
1	1185	1265	1775	1593	1821	1746
1	1488	1536	2091	2268	1546	1304
1	936	923	1257	1468	1443	1643
1	939	1005	2523	1216	2631	1562
1	629	638	1062	1343	1410	1530
1	1060	1502	1661	1650	1515	2238
1	957	900	1572	1306	1885	2023
1	1950	1388	1548	2314	2128	2025
1	851	2180	1344	1123	1336	1186
1	1042	1115	1031	1014	1116	1238
1	1270	1374	1617	1829	1354	1696
1	1516	1638	1892	1878	1958	1919
1	1025	1160	1586	1409	1449	1182
1	1134	1183	1403	1275	1529	1727
1	855	1011	1559	1307	1093	1263
1	911	739	1742	903	864	1028
1	839	937	803	980	1722	1526
1	1306	4448	1503	1591	1626	1754
1	658	822	943	774	1191	1283
1	1006	1085	1381	873	2247	2536
1	1259	1575	1091	1163	2364	1727
1	1088	1094	1277	1558	1307	1176
1	1081	1166	1394	1587	1820	1342
1	778	890	1139	2344	870	933
1	823	889	931	1091	1167	1072
2	1048	991	1284	1218	1210	1322
2	746	633	739	627	826	897
2	609	623	846	1082	1246	997
2	490	597	658	763	803	766
2	728	618	1988	1080	1209	1370
2	1105	1001	1275	1265	1396	1500
2	567	684	894	742	1328	1043
2	631	711	976	1087	1303	1386
2	596	643	1004	920	1127	1023
2	1451	1299	1494	1326	1899	1745
2	757	674	398	839	910	304
2	876	965	755	913	965	795
2	845	920	1178	944	1070	1262
2	1012	840	1234	877	1089	1305
2	715	844	763	857	1107	1009
2	817	647	359	1008	924	794
2	606	681	771	689	1140	1141
2	723	780	666	758	786	792
2	744	915	1473	1055	1199	1156
2	1006	1095	1411	1098	1047	1064
2	2099	825	915	1021	1289	1095
2	1083	1088	1659	1220	1552	1480
2	540	615	593	672	786	1021
2	964	1083	1542	1302	1354	1852
2	925	674	958	945	918	1399
2	1220	1284	2008	1673	1624	1743
2	628	618	1100	1613	1123	906
2	938	1515	2227	1155	2256	1551
3	740	698	1107	1172	1150	1088

```
G
R
A
D
E        USL        USH        UBL        UBH        UTL        UTH

3        621        659        765        722        882        363
3        697        685        741        818        942        934
3        518        796       1113        990       1284       1019
3        846        843       1073        944        899        954
3       1403        832       1351       1553       1048       1314
3        870        688       1015        868        964        989
3        708        626       1055        993       1082       1147
3        705        684        840        768       1028        918
3       1081        901       1104       1254       1290       1267
3        693        685        876        809        867        904
3       1062       1065       1244       1238       1303       1333
3        590        609        648        895        738        680
3        671        660        716        607        616        696
3        896        976       1164       1195       1320       1032
3        719        720        754        765       1057        941
3       1236        889       1194       1129       1450       1588
3       1089        989        825        813        990       1168
3        908        780       1030       1132       1038       1011
3        785        800        872        848        890        861
3        857        777        918        972       2062       1422
3        811        593       1157        871       1005        861
3        958        681        974        774       1002       1009
3        754        711        748        748        949        834
3        748        722       1010        812        925        945
3        686        807        783        816       1005        786
3        990        983       1337       1095       1083       1104
3        584        532        721        663        741        815

Number of cases read:  84    Number of cases listed:  84
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