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Phonological Recoding and Orthographic Learning: A Direct Test of the Self-Teaching Hypothesis

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According to the self-teaching hypothesis (Share, 1995), word-specific orthographic representations are acquired primarily as a result of the self-teaching opportunities provided by the phonological recoding of novel letter strings. This hypothesis was tested by asking normal second graders to read aloud short texts containing embedded pseudoword targets. Three days later, target spellings were correctly identified more often, named more quickly, and spelled more accurately than alternate homophonic spellings. Experiment 2 examined whether this rapid orthographic learning can be attributed to mere visual exposure to target strings. It was found that viewing the target letter strings under conditions designed to minimize phonological processing significantly attenuated orthographic learning. Experiment 3 went on to show that this reduced orthographic learning was not attributable to alternative nonphonological factors (brief exposure durations or decontextualized presentation). The results of a fourth experiment suggested that the contribution of pure visual exposure to orthographic learning is marginal. It was concluded that phonological recoding is critical to the acquisition of word-specific orthographic representations as proposed by the self-teaching hypothesis.

Key Words: reading development; orthographic learning; phonology; self-teaching; children.

An extensive research literature has linked individual differences in reading ability to basic phonological processing (speech perception, immediate, short-term and long-term memory for speech-based information) and to phonological awareness (awareness of the segmental nature of speech) (for reviews see Goswami & Bryant, 1990; Shankweiler, Crain, Brady, & Macaruso, 1992; Share, 1995; Snowling, 1991; Stanovich, 1992; Wagner & Torgesen, 1987). The strength of these relationships clearly indicates that any plausible model of reading acquisition must assign phonology a leading role. Unfortunately, the explanatory coherence of this literature is considerably diminished by a lack of consensus regarding the specific role of phonology in learning to read. Consid-

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eration of some of the common explanations proposed to account for the role of phonology in early reading acquisition (such as a developmentally obligatory stage of print-to-sound translation) reveals just how poorly the evidence linking reading and phonology is grounded in a tenable model of reading acquisition (see Barron, 1986; Jorm & Share, 1983; Share & Stanovich, 1995).

An alternative to traditional accounts regarding the role of phonology in early reading is the “self-teaching” model proposed by Jorm and Share (Jorm & Share, 1983; Share, 1995; Share & Jorm, 1987). According to this model, phonological recoding (print-to-sound translation) performs a self-teaching function enabling the learner to acquire the detailed orthographic representations necessary for fast, efficient visual word recognition. Although direct whole-word instruction and contextual guessing have also been proposed as options for developing orthographic knowledge, both theoretical and practical considerations suggest that only phonological recoding offers a viable route to printed word learning (see Share, 1995).

According to the self-teaching hypothesis, each successful identification (decoding) of a new word in the course of a child’s independent reading of text is assumed to provide an opportunity to acquire the word-specific orthographic information on which skilled visual word recognition is founded. Relatively few exposures appear to be sufficient for acquiring orthographic representations, both for skilled readers (Brooks, 1977) and for young children (Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983, 1989). In this way, phonological recoding acts as a self-teaching device or built-in teacher enabling a child to independently develop the word-specific orthographic representations essential to skilled reading and spelling.

The proposed self-teaching function of phonological recoding has several key features pertinent to the investigation reported below. First, the developmental role of phonological recoding (as distinct from the development of phonological recoding itself) is seen as *item-based* rather than *stage-based.*[1] Traditionally, researchers have responded to the question of how children access the meaning of printed words by proposing a developmental progression, often in the form of a transition from a phonological to visual “stage.” But stage-based theories have not fared well in light of empirical findings (Barron, 1986; Jorm & Share, 1983). It may be more appropriate to ask how children get meaning from *which* words. Adopting an item-based perspective, the self-teaching hypothesis argues that the process of word recognition will depend primarily on the frequency to which a child has been exposed to a particular word together with the nature and success of item identification. Because orthographic information is acquired rapidly

[1] There are clearly important developmental changes in decoding skill which many authors have described in terms of stages (see, e.g., Ehri, 1995; Frith, 1985), although others see these changes as more continuous (see, e.g., Share’s 1995 discussion of the “lexicalization” of decoding skill). The view proposed here regarding the *item-based* role of phonological recoding *in the acquisition of word-specific orthographic representations* is entirely compatible with either continuous or stage-like conceptions of decoding development.

(Brooks, 1977; Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983, 1989), high frequency items are likely to be recognized by sight with minimal phonological processing from the very earliest stages of reading acquisition. Novel and less familiar items for which the child has yet to consolidate orthographic representations will be more dependent on phonology. Because the frequency range in children's natural reading materials is so very wide (Carroll, Davies, & Richman, 1971), reliance on phonological recoding will vary according to the distribution of item familiarities.

This phonology by familiarity account resolves much of the conflicting evidence regarding the relative reliance on visual versus phonological processing in young readers' word recognition. A majority of words in natural text will be recognized visually by virtue of their high frequencies, while the smaller number of low frequency items will provide opportunities for self-teaching with minimal disruption of ongoing comprehension processes. Because so very many words occur so very rarely in print, the self-teaching opportunities afforded by phonological recoding may well represent the "cutting edge" of reading development not merely for the beginner, but throughout the entire ability range.

A second feature of self-teaching is early onset; beginning reading is beginning self-teaching (Share & Stanovich, 1995). A growing number of studies now suggest that some rudimentary self-teaching skills, perhaps sufficient to establish primitive orthographic representations of the kind discussed by Perfetti (1992), may exist at the very earliest stages of learning to read even before a child possesses any decoding skill in the conventional sense of being able to sound out and blend even simple pseudowords (Ehri & Wilce, 1985, 1987; Morris, 1992; Stuart & Coltheart, 1988). This early self-teaching depends on three factors: Letter–sound knowledge, some minimal phonological sensitivity, and the ability to utilize contextual information to determine exact word pronuciations on the basis of partial decodings.

Ehri and others (Ehri & Sweet, 1991; Ehri & Wilce, 1985, 1987; Rack, Hulme, Snowling, & Wightman, 1994; Scott & Ehri, 1990) have demonstrated that even kindergarten children are capable of learning words on a phonetic rather than on a visual basis provided they have some knowledge of spelling–sound relationships. For example, knowledge of the names of the letters J and L may enable a child to read the word JAIL even in the absence of blending skill. A partial decoding strategy, however, cannot succeed on the basis of letter–sound knowledge alone. It necessarily depends on the ability to recognize identity between learned letter names or sounds and phonological segments in spoken words. A child who is able to generate words beginning with a given sound and who has also acquired a basic knowledge of letter–sound correspondences will be in a position to generate a plausible candidate for a novel item. A child oblivious to the phonemic structure of speech, that is, for whom spoken words are indivisible wholes, will have no way of generating a candidate pronunciation for an unfamiliar letter string. The joint role of letter–sound knowledge and phonological sensitivity is consistent with the wealth of evidence indicating that these two factors are critical *corequisites* in reading acquisition (e.g., Bradley & Bryant, 1983; Ehri & Sweet, 1991; Hatcher, Hulme, & Ellis, 1994; Tunmer & Nesdale, 1988).

Third, self-teaching involves at least two component processes—phonological and orthographic. The phonological component is simply the ability to use knowledge of spelling–sound relationships to identify unfamiliar words. This ability may well represent the *sine qua non* of reading acquisition (see Share, 1995). However, over and above the ability to decode unfamiliar words, there exist individual differences in the speed and accuracy with which word-specific (and general orthographic) knowledge is assimilated (Barker, Torgesen, & Wagner, 1992; Cunningham & Stanovich, 1990a, 1993; Olson, Wise, Connors, & Rack, 1990; Olson, Forsberg, Wise, & Rack, 1994; Stanovich, West, & Cunningham, 1991). The common metric of orthographic ability is typically spelling knowledge (often assessed with tasks such as orthographic choice and homophone choice). These measures of what might be termed "crystallized" orthographic ability reflect not only those cognitive factors such as visual analysis and memory (and possibly also reflectivity/impulsivity) that determine how quickly and accurately orthographic representations are established, but also instructional/environmental and print exposure variables. These visual/orthographic processes, however, will depend heavily on the successful operation of the phonological component. Thus, visual/orthographic processing is regarded not merely as a second source of variance, but as a *secondary* source of individual differences in reading acquisition.

Although there exists an abundance of indirect evidence in support of the self-teaching notion (see Share, 1995), no direct test has yet been undertaken. A handful of studies, however, have reported experimental data consistent with the self-teaching hypothesis.

In a seminal series of experiments, Reitsma (1983) taught third graders pseudoword names for fictitious animals and fruits. Half of these items were presented auditorily and half both auditorily and visually. Following a 90-min delay, test items were briefly relearned, then presented visually in a semantic (animal/fruit) categorization task in which all items appeared six times. Classification times for the items not seen in printed form were significantly slower only for the first three presentations, that is, by the fourth trial response latencies had effectively converged with the items learned in both visual and spoken form, suggesting rapid learning of orthographic forms. In a second study (Reitsma, 1983, Experiment 2), second graders were taught to read a set of pseudowords after first being familiarized with their spoken forms. Subjects then practiced reading the pseudowords (in isolation) either four or eight times. Three days later, target spellings were named significantly faster than homophonic spellings but only for the group who practiced reading the targets eight times. A third study (Experiment 3) compared word learning in skilled and unskilled first grade readers and an older reading level-matched group of disabled readers. Twenty words judged to be familiar in spoken form but unfamiliar in print were presented in meaningful sentences which were read and reread two, four, or six times over two successive days. Reading errors were corrected by the experimenter (Reitsma, personal communication, 1994). Three days later both the original spellings and homophonic spellings were presented for naming. Both groups of first graders read target spellings more quickly and more accurately for words practiced four or six times but not for words practiced only twice or not at all (controls). There was no evidence of orthographic learning among disabled readers either in errors or in naming speed, although sensitivity to word-specific information was evident in a set of high frequency words which were read significantly faster than their corresponding homophonic (mis)spellings.

In two further follow-up studies summarized in Reitsma (1989), normal first graders and older reading level-matched disabled readers again practiced reading unfamiliar real words 0, 2, 4, or 6 times. As before, the younger beginning readers, but not the older disabled readers, showed the familiar divergence in target/homophone naming times with increasing practice. In these data, a naming time difference was already apparent after only two exposures. Response time differences for words and homophones as a function of practice were also correlated significantly with scores on a word reading fluency test for both groups of readers.[2] A significant correlation between naming time differences and performance on a test of oral pseudoword repetition led Reitsma to conclude that acquisition of word-specific knowledge depends partly on efficient phonological processing. In a second experiment, normal first graders and older disabled readers practiced reading unfamiliar real words 0, 3, 9, or 18 times. In this study, the naming time effect was again evident among the normal readers but only after nine (but not three) exposures. Once again, there was no evidence of orthographic learning among the older disabled readers even after 18 exposures. The effects of phonemic priming were found to decline with increasing practice for the normal beginners suggesting that their acquisition of word-specific orthographic information was accompanied by a diminishing reliance on phonology. For disabled readers, the benefits of a related phonemic prime were consistent across all exposures.

Together, these studies suggest that relatively few exposures are sufficient for the acquisition of word-specific orthographic information among normal readers, but not disabled readers. Similar findings have since been reported by Manis (1985) and more recently by Ehri and Saltmarsh (1995).

Manis (1985) taught normal and disabled Grade 5 and 6 readers both the meaning and pronunciation of low-frequency words varying in regularity. Chil-

[2] In his earlier (1983) work, Reitsma failed to find a relationship between orthographic learning and reading fluency. However, the earlier analysis was based on between-group comparisons with relatively small samples (9, 9, and 13) rather than the within-group correlations used in this later study.

dren were first taught the meanings of these items, then were presented with their printed forms for pronunciation. All errors were corrected and reread. In two further sessions, children were retrained briefly on both the meaning and pronunciation of the test items before being given two naming tasks (immediate and delayed). By the third session (after four visual exposures and six spoken exposures), naming times (and errors) for the normal readers (but not the disabled readers) had virtually converged on the naming times for a set of high-frequency control words. Declining regularity and length effects also suggested that word-specific orthographic representations had become rapidly acquired by the normal readers.

Ehri and Saltmarsh (1995) taught skilled and less skilled first graders and older disabled readers to read simplified phonetic spellings for a set of real words (e.g., MESNGR, STUPD). Following Reitsma (1983), original and altered spellings were presented in a naming task 3 days later. Altered spellings included both phonetic equivalents (e.g., CRADL/KRADL) and phonetically close but non-equivalent spellings (e.g., BAMBU/PAMBU, STUPD/STUP). All target spellings were directly taught by the experimenter who also explained the meaning of each word. The test list was then practiced between 10 and 12 times over consecutive days, with all mispronunciations corrected and reread. Skilled first grade readers required only four practice trials to achieve errorless performance on the entire list, while the other two groups each required over twice this number of trials. Both nondisabled groups, but not the older disabled readers, read the original spellings significantly faster than the fully homophonic spellings. For phonetically divergent spellings, all three groups were significantly faster on the original spellings.

Although all the experimental investigations reviewed above are certainly consistent with the hypothesis that word-specific orthographic representations are acquired *by virtue of the self-teaching opportunities afforded by successful decoding,* the data are inconclusive for several reasons.

First, in all these studies correct item pronunciation was either supplied by the experimenter in an initial training phase or corrected if an error occurred. Moreover, the experimental procedure *obliged* the child to decode all target strings. Self-teaching is assumed to operate when a child is independently reading connected text for meaning. In everyday reading situations, children may (a) choose to ignore unfamiliar words which can often be skipped without penalizing overall comprehension, (b) may guess (correctly or incorrectly) on the basis of prior context and/or prior knowledge, or (c) make *uncorrected* misreadings. Remarkably, a massive body of evidence shows that normal young readers are able to phonologically recode novel letter strings such as pseudowords *when obliged to,* but not a single study directly demonstrating that this knowledge is actually applied in independent reading. The word learning data presented above, therefore, need replicating under more naturalistic conditions in which neither training nor corrective feedback is supplied.

From the point of view of the self-teaching hypothesis, there is a second, fundamental shortcoming as regards the word learning studies reviewed above. Orthographic learning may be attributable to mere visual attention to the target strings rather than to the decoding process per se. Because the pronunciation of unfamiliar letter strings often involves letter-by-letter processing of visual detail, simply seeing rather than saying the letter string may be responsible for orthographic learning. Although Reitsma's (1989) finding of significant correlations between orthographic learning on the one hand and both reading fluency and oral pseudoword repetition on the other is certainly suggestive, this alternative hypothesis is difficult to rule out in any of these experimental studies.

The present study set out to determine whether the basic word learning finding reported by Reitsma, Manis, Ehri, and Saltmarsh extends to unassisted oral reading of connected text (Experiment 1). The alternative visual attention hypothesis was also evaluated in the present investigation (Experiments 2, 3, and 4).

The basic experimental paradigm consisted of multiple presentations of target words embedded in short texts. The targets were simply novel letter strings (pseudowords) representing fictitious names for places, animals, fruits, etc. Normal second grade readers were asked to read aloud a set of "stories" and decide which they liked best. No assistance or feedback was given at any stage during text reading. Comprehension questions followed each passage to ensure that children understood the text. Each text contained an orthographic target appearing either four or six times. According to the self-teaching hypothesis, children who are able to decode the targets will begin to acquire a knowledge of their orthographic forms (spellings), such that the correct form will be named more quickly and spelled more accurately than alternative homophonic spellings.

Targets were preselected in a pilot study to ensure that there existed no preferences for either of two homophonic spellings. As an additional precaution, half the children were assigned one spelling and half the other. This ensured that any advantage for a particular spelling of a target would be offset when this same spelling appeared as a homophonic foil.

Following Reitsma's (1983) procedure, orthographic learning was assessed 3 days after text reading. Three measures were employed. The first, orthographic choice, required children to select the correct spelling of the target item from among four alternatives (the original spelling, a homophonic foil, and two nonhomophonic spellings containing either substituted or transposed letters). The second measure of orthographic learning simply required children to read aloud a list of words appearing on a computer screen. Embedded in this list were both the original and homophonic spellings of the targets. Finally, each child was asked to reproduce from memory (write) the target spelling.

Forty normal second grade readers participated in this test of the self-teaching hypothesis.

EXPERIMENT 1

Method

Sample

The sample was drawn from a regular school in a relatively advantaged neighborhood in Haifa. There were three second grade classes containing a total of 113 children. Five children who were recent immigrants to the country and four others with known or suspected learning or developmental disabilities were excluded from the prospective sample pool. From the remaining pool of 104 children, 40 names were randomly selected from the class rolls. Of these 40 children, one girl was found to have a reading difficulty that precluded participation in the study. Three other children had to be replaced owing to absence from school on one of the designated posttesting days. In these cases, the next child on the class list was substituted. No child had to be excluded because of poor reading comprehension or noncompliance.

Targets and Texts

A candidate pool of 50 homophonic pseudowords was first developed containing five candidate pairs of homophonic pseudowords in each of the following 10 categories: Animals, cities, flowers, fruit, cars, stars, coins, musical instruments, peoples (nations), and personal names. These pairs were presented as an orthographic preference task to a total of 118 second graders from two schools of comparable socioeconomic status to the school in which the main experiment was carried out. Within each of the 10 categories, the pair with preferences closest to the 50:50 mark were selected as target items. The average difference in preferences for the two alternate spellings of the pairs finally selected was only 3.9%.

The 10 designated target pairs ranged in length from two to four syllables and from three to five letters (average 4.1). Each individual letter string included two letters each of which represented a consonantal phoneme which could be transcribed by two alternate graphemes.[3] Included in this set of 10 target items were five of the six homophonic–grapheme pairs that exist in Hebrew orthography.

[3] This study examined orthographic learning of purely consonantal graphemic information because Hebrew orthography is a consonantal alphabet in which (optional) vowel diacritics (or "points") have only a subsidiary status (appearing mostly below letters). This reflects the fact that in Semitic morphology, the semantic core of content words is represented by a purely consonantal root, with vowel information conveying mostly grammatical inflections such as person, number and gender. This difference between consonants and vowels is reflected not only in the speech patterns of native Hebrew speakers, who often exchange stem-internal vowels in spoken word production (Ravid, 1995), but also in the fact that skilled readers have been shown to be largely insensitive to vowel identity (Shimron & Navon, 1982), relying on direct recognition of consonantal roots (Frost & Bentin, 1992; Bentin & Frost, 1995).

These alternate letters occurred at all positions (from initial to final) across target strings.

Ten short texts (narrative and expository) were then composed in which each target appeared six times (see sample text in Appendix). Parallel texts with only four exposures were created by substituting either a synonym or a preposition for two of the targets (for example, “Would you like to live in Akunia?” was altered to “Would you like to live in this town?”). Texts ranged in length from 94 to 170 words (mean length 126).

All texts were fully pointed, that is, included vowel diacritics, and hence had near perfect one-to-one grapheme–phoneme correspondence (Feitelson, 1988; Navon & Shimron, 1984; Share & Levin, in press).

Posttest Measures of Orthographic Learning

Three measures of orthographic learning were administered 3 days after text reading.

Orthographic choice. Each child was presented with four alternate spellings of the target word: (1) The original target spelling seen earlier in the test text, (2) a homophonic spelling in which both “target” letters were replaced by their homophonic alternatives, (3) a letter substitution in which a single letter was replaced by a visually similar letter, and (4) a letter transposition in which two adjacent letters were transposed. As noted earlier, for half of the sample the homophonic spelling was the “correct” target spelling seen 3 days earlier. Items were presented in a slightly different font to that used in the original texts.

Naming. Children were asked to name a series of words presented on computer screen one at a time. The target spellings, both original and homophonic, were embedded in a longer list of 60 items designed to reflect the natural range and distribution of word frequency in children’s reading material. Thus, several high frequency function words appeared in the list several times as in natural text. Each list contained all targets seen 3 days earlier, together with their homophone foils. Each spelling (both target and homophone) was presented twice to ensure an adequate number of latencies on which to base statistical analyses. To control for differential priming, the order of presentation in each list was target/homophone/homophone/target for half the sample and homophone/target/target/homophone for the other half. This arrangement equates the total number of times each of the two alternate spellings is phonologically (and, of course, orthographically) primed. Each word was presented (fully pointed) in the centre of a computer screen and remained visible until removed by activation of the voice key. The intertrial interval was 1000 ms.

Spelling. The third gauge of orthographic learning required children to spell the target spelling.

Background Reading and Cognitive Measures

Peabody Picture Vocabulary (Solberg & Nevo, 1979). This is the Israeli adaptation of the Peabody test. Unfortunately, no reliable norms are available for children at this age.

Pseudoword naming accuracy (Shatil, 1997). This test of untimed oral reading included 114 pseudowords ranging in length from one to five syllables. These items were derived from a real word by changing one or more consonant letters. Testing was discontinued after six consecutive errors.

Stanford–Binet Bead Memory Test (Stanford–Binet, 4th ed., 1988). In this test of visual short-term memory, a child is shown a photograph of a sequence of beads of different shapes, orientation, and color arrayed vertically on a stick. The child's task is to study the sequence for 5 s and then reproduce it from memory by selecting the correct beads (from an assortment placed before him/her on the table) and arranging them in the right order and orientation. String length ranged from two to seven items. Raw scores were converted to age-based standard scores (mean 50) according to the test manual.

Pseudoword naming speed (Shatil, 1997). Seventy pseudowords were presented in list format and the child was instructed to read as quickly and accurately as possible until told to stop (after 60 s). Half the items were monosyllabic and half were bisyllabic. Reading rate in words per minute was scored as the number of words read aloud within 1 min minus the number of errors.

Procedure

Testing was conducted on an individual basis in a quiet resource room adjacent to the Grade 2 classrooms. The basic testing procedure involved the reading of five texts, followed 3 days later by posttesting. After an interval of at least 10 days, the remaining five texts were read, followed by the final posttest session 3 days later. Two additional sessions were devoted to the assessment of background reading and cognitive abilities.

In the first text-reading session, the task was explained as follows; "I want you to read aloud some stories and tell me which one you liked best. Try and read them all by yourself. Be sure you understand the stories because I'm going to ask you some questions afterwards, O.K.?" The only assistance given was with reading the title of the passage. No further help of any kind was given during story reading, neither praise nor corrective feedback. Any child who explicitly sought help identifying a word was asked to try their best to read it by themselves. Permission was requested (and, in all cases, granted) to tape-record story reading.

Following text reading, children were asked five factual questions which could be answered only on the basis of text content, not from general knowledge (see Appendix). Comprehension scores across all 10 passages averaged 88% (range 74 to 100%). Thus, no child failed to understand the basic content of the passages they were reading. The average number of errors per passage reading *nontarget* words was 1.8, thus reading accuracy (targets excluded) in this sample averaged

98.5%.[4] The median reading time for these passages was slightly longer than $1\frac{1}{2}$ min (98 s). In short, these texts were well within the reading capabilities of this Grade 2 sample.

Three days later, the child was seen again to determine the extent to which the new orthographic information had been assimilated.

Posttests

Orthographic choice. Each child in turn was first asked if s/he remembered the story about the fruit/town/flower, etc., and then the four alternative spellings of the target word were presented: "Here are four words that all look very much alike, but if you look carefully you'll see that they're all different. One of these words, and only one, is the same as the name of the town/fruit/flower you read in the story 3 days ago. Make sure to look very carefully at each word, one at a time, then tell me which one is the right one." No corrective feedback was given in response to a child's choice. Locations of the four alternatives were rotated clockwise from child to child. The order of presenting target sets was similarly varied across children.

Naming. Immediately following orthographic choice, the child was then seated in front of a desktop computer and told that s/he was going to read aloud some words on the computer. The words which would appear in the middle of the screen, were to be read as quickly and as accurately as possible. The child was asked to hold and speak into a microphone which was connected to a voice key. Twelve practice trials preceded the test list. Naming responses were recorded manually by the experimenter who sat next to the child. List reading was also tape-recorded for later cross-checking. No feedback was given during word naming.

Following naming, the child was asked to write the name of the town/flower/fruit, etc. Every attempt was made to elicit the child's own representation of the target words. First, after reminding the child about the topic of a particular story (e.g., "Do you remember the story you read to me about the hottest town in the world?"), the examiner asked the child to write the name of the town/fruit/animal etc. If the child was unable to recall the name, the first syllable was supplied. If this too failed to elicit the cued word, the target was then supplied in full. No attempt was made to praise, modify, or correct any written response.

There were a total of 10 base stories, each in four versions (four or six target exposures, each in two alternate spellings). Since each child read only one version of each story, a sample of 40 subjects, each reading all 10 stories, ensured 10 observations per text. In each of the two story-reading sessions, a child read a set of five texts, with set order counterbalanced. Within each set, both story order and text version (exposure/spelling) were counterbalanced across the

[4] This high level of oral reading accuracy is consistent with other data for Hebrew readers at this age (see Share & Levin, in press) and can be attributed to the near perfect one-to-one letter–sound correspondence in pointed (fully voweled) Hebrew which is normally mastered by the end of Grade 1.

TABLE 1
Background Reading and Cognitive Characteristics of 40 Children Participating in Experiment 1

Variable	Mean	*SD*	Range
Age in years and months	8:0	3.5 months	7:6–8:6
Gender	19 girls, 21 boys		
Peabody raw score	61.1	9.10	47–88
Stanford–Binet Bead Memory (standard age scores)	52.5	9.06	37–73
Pseudoword naming accuracy (maximum score 114)	90.7	13.87	49–108
Pseudoword naming rate in words per minute	32.5	10.53	16–59

sample such that each of the 40 texts appeared exactly once in each serial position from 1 to 10.

Two separate sessions devoted to assessing reading and cognitive status were also carried out on an individual basis.

Results

Basic background data on this sample's reading-related and cognitive abilities appear in Table 1.

It can be seen that the Stanford–Binet Bead Memory results in this sample are very close to the North American mean for children of this age. As noted earlier, no reliable Peabody norms are available at this age. Pseudoword reading accuracy is at levels typical for normal readers at this age when reading pointed Hebrew script (see Share & Levin, in press).

Identification of Targets during Text Reading

The self-teaching hypothesis presupposes that children are not merely *able* to decode novel orthographic strings (as witnessed in successful pseudoword reading) but actually *apply* knowledge of symbol–sound relationships when reading text rather than simply guessing or skipping unfamiliar items.

The data indicated that for a regular orthography such as pointed Hebrew, at least, the assumption that readers normally apply their knowledge of symbol–sound relationships when reading text is correct. Overall decoding accuracy for target words (ignoring vowel errors, see Footnote 2) was 84.4% (*SD,* 10.4; range, 62.5–100). Thus, most words were successfully decoded when encountered in text.

Orthographic Choice

Selection rates for each of the four spellings (target, homophone, transposition, and substitution) appear in Table 2.

TABLE 2
Posttest Orthographic Choices (Correct Targets, Homophones, Transpositions, and Substitutions) in Experiment 1

Exposures	Target	Homophone	Transposition	Substitution
Overall (n = 400)	73.5% (294)	16.75% (67)	6.25% (25)	3.5% (14)
Four (n = 200)	68.5% (137)	18.0% (36)	9.0% (18)	4.5% (9)
Six (n = 200)	78.5% (157)	15.5% (31)	3.5% (7)	2.5% (5)

If no orthographic learning occurred, and choices were merely random, each of the four alternatives should be selected with the same frequency (25%). A chi-square test indicated that responses were not evenly distributed across the four alternatives ($\chi^2 = 517.5$, $df = 3$). Specifically, the proportion of correct choices (combining both exposure levels) was significantly beyond chance ($z = 22.4$, $n = 400$). So too were the separate four-exposure ($z = 14.2$, $n = 200$) and six-exposure conditions ($z = 17.5$, $n = 200$).[5] Table 2 shows that target choices outnumbered each of the alternative choices by at least 3 to 1.

The correct spelling, however, is not merely orthographically correct but, of course, phonologically identical to the original target word. It is apparent from Table 2 that all spellings that matched the target pronunciation enjoyed a decisive edge over phonologically incorrect spellings (transpositions and substitutions) which were relatively rare. Thus, phonological learning is clearly evident. To demonstrate that *orthographic* learning per se has occurred, it is therefore necessary to demonstrate that the correct target was selected significantly more frequently that its homophonic rival.

Table 2 shows that target spellings were consistently chosen three times as often as homophonic foils, and these differences were highly significant for the overall analysis ($z = 11.93$, $n = 361$), the four-exposure condition ($z = 7.68$, $n = 173$), and the six-exposure condition ($z = 9.19$, $n = 188$).[6] Clearly, orthographic learning has occurred. The difference between the four-exposure and six-exposure conditions was not significant ($z = 1.05$, n.s.). Thus, four or fewer exposures seem sufficient for orthographic learning to occur, as demonstrated more than a decade ago by Reitsma (1983). The strong preference for the correct target was reproduced in each and every one of the 10 base target pairs. Pooling the number of both exposures and alternate spellings for each target word, the percentage of correct targets identified (as a proportion of all phonologically plausible choices—targets plus homophones) ranged from 68.4 to 91.7%. Each of these figures was significantly greater than the corresponding proportion of homophone

[5] Unless explicitly indicated as nonsignificant, all statistical results were significant at the .01 level.

[6] In these analyses, the proportion of target choices was calculated as the proportion of all phonologically correct choices (i.e., targets and homophones). These proportions were then compared to an expected value of .5. The actual proportions were 81.4, 79.2, and 83.5% for overall, four-exposure, and six-exposure analyses, respectively.

TABLE 3
Naming Latencies in Milliseconds for Targets and Homophonic Foils in Experiment 1

	Target	Homophone	
Exposure	Mean (*SD*)	Mean (*SD*)	Difference
Overall (n = 40)	816 (338)	874 (408)	58
Four (n = 29)	793 (253)	853 (274)	60
Six (n = 31)	842 (366)	893 (439)	51

choices (minimum $z = 4.54$). It can be concluded that successful target identification across subjects was replicated at the item level. Even at the level of the 40 individual texts (10 base texts each in four versions—exposure by spelling), correct target choices outnumbered homophone choices in each and every case.

Naming Errors

Each child read a total of 20 targets (10 targets each presented twice) and 20 homophone foils. Only fully accurate pronunciations (consonants *and* vowels) were accepted as correct.[7] (Self-corrections were also accepted.) Trials lost due to equipment malfunction were 2.6% for targets and 2.3% for foils. Targets and foils were read with similar overall accuracy (targets, 67.8%, homophones, 68.8%; $t < 1.0$). Thus, there was no difference in the accuracy with which either the original spelling or its homophonic alternative was read. There was, however, a significant difference in vocalization onset times.

Naming Latencies

Means and standard deviations of individual subjects' median naming latencies (correct pronunciations only) appear in Table 3. Latencies for targets were, on average, 58 ms faster than latencies for their homophonic foils, and this difference was significant ($t = 2.14$, $df = 39$, $p = .019$, one-tailed).

Although the number of valid reaction times was unacceptably low when the four-exposure and six-exposure conditions are considered separately, these data are included in Table 3 for the sake of completeness. It can be seen that the separate results for each of these conditions essentially replicates the overall picture. However, in both cases, the average number of valid reaction times per cell was only six to seven, with, of course, many instances of even lower figures. It was decided to include in this analysis only cases with five or more valid times each for both targets and homophones. There were 29 such cases in the four-exposure condition and 31 in the six-exposure condition. The 60-ms advantage of targets over homophones in the four-exposure condition was significant (t =

[7] This strict criterion was adopted to ensure comparability of pronunciation latencies for both targets and homophones; that is, latencies were based on identical articulatory sequences.

TABLE 4
Posttest Spelling According to Exact Whole-Word Criterion

Exposure	Target	Homophone	Nonphonological	Other	Total nonmissing
Four	51% (79/155)	18% (18/155)	40	58	195
Six	54% (82/152)	14% (22/152)	47	48	199
Overall	52% (161/307)	13% (40/307)	87	106	394

Note. Percentages are based on the total number of phonologically accurate reproductions.

2.31, $df = 28$, $p = .014$, one-tailed), but not the 51-ms difference in the six-exposure condition ($t = 1.13$, $df = 30$, $p = .13$, one-tailed), owing to larger standard deviations.

Overall, then, the naming time data replicated the findings of Reitsma (1983) and Ehri and Saltmarsh (1995) with overall pronunciation times significantly faster for target spellings than for alternative homophonic spellings. Moreover, this speed advantage was statistically reliable even after only four exposures (cf. Reitsma, 1983). This latency effect, moreover, cannot be attributed to a speed–accuracy trade-off since no differences in pronunciation errors were found.

Spelling

If word-specific orthographic information is acquired in the course of decoding novel words in text, then children should be able to reproduce target spellings beyond a chance level.

Spellings were scored according to both a whole-word (Table 4) and per-letter criterion (Table 5).

Whole-Word Scoring

According to this scoring method, only exact reproductions were accepted as accurate. Any letter additions, omissions, substitutions or transpositions, whether in target or nontarget letters, were disqualified.

If children successfully recall the correct phonological form of the targets, but spellings are entirely random, then the probability of producing *both* correct target (homophonic) letters is .25, since each of the corresponding phonemes could be transcribed in either of two ways. Eighty-seven spellings did not preserve exact pronunciation, while another six were lost due to experimenter error.

Out of a total of 307 phonologically plausible spellings, 52.4% (161) were faithful reproductions of the target spelling. This proportion was well beyond the 25% chance level ($z = 11.1$).

By the same logic that predicts accurate target spellings occurring by chance around 25% of the time, spellings that exactly match the alternate homophonic spelling should also occur at the same chance rate of 25%. Thus, a comparison

TABLE 5
Posttest Spelling Performance on a Per-Letter Basis (Homophonic Target Letters Only)

Exposures	Target	Homophone	Other	Total nonmissing
Four	266 (68.2%)	110 (28.2%)	14 (3.6%)	390
Six	263 (66.1%)	122 (30.7%)	13 (3.3%)	398
Overall	529 (67.1%)	232 (29.4%)	27 (3.4%)	788

of the rates of target and homophone spellings provides another check of orthographic learning.

Forty (13%) of the 307 phonologically plausible spellings were "fully" homophonic, that is, exactly matched the homophone foil. As in the orthographic choice task, target spellings outnumbered homophonic spellings by over 3 to 1. This difference between the two alternate spellings (52% versus 13%) was significant ($z = 5.31$).

There was very little difference between the four-exposure (51.0%) and the six-exposure (53.9%) conditions, with each significantly beyond chance (four-exposure, $z = 7.47$; six-exposure, $z = 8.24$), and significantly greater than the corresponding homophone spellings (four-exposure, $z = 5.28$; six-exposure, $z = 5.13$). The difference between the four- and six-exposure conditions, however, was not significant ($z < 1.0$). Once again, it appears that four encounters with a novel letter string seem to be adequate for orthographic learning, with only marginal benefits for an additional two exposures.

Per-Letter Scoring

This second analysis focused exclusively on the two homophonic target letters in each word. Any other added, missing, or even transposed letters were ignored. Each of these two letters was scored separately. Results are presented in Table 5.

The overall accuracy of target letter reproductions (67.1%) was significantly greater than either the 50% chance level ($z = 9.62$) or the rate of homophonic spellings (29.4%, $z = 10.59$). As with the whole-word scoring, there was little difference between the four-exposure and six-exposure results, each being significantly above both the 50% chance level (four-exposure, $z = 7.19$; six-exposure, $z = 6.42$) and the rate of "fully" homophonic spellings (four-exposure, $z = 7.91$; six-exposure, $z = 7.07$).

Target Letter Position

This analysis examined the possibility that acquisition of orthographic information was position-dependent. The first of the two critical letters in each of the 10 base words was invariably the word-initial letter. The other target letter appeared in positions 2 to 5 (average 3.4).

The rate of correct reproductions of initial target letters was 66.2% (251 out of

379 phonologically plausible spellings) compared to 72.8% for noninitial letters. This difference was not significant ($z < 1.0$).

Although the preceding analysis is confounded by different letter identities, the absence of an effect of target letter position is consistent with the view that printed Hebrew has minimal orthographic redundancy (Share & Levin, in press; Shimron & Sivan, 1994)[8] and consequently necessitates exhaustive, letter-by-letter processing.

Discussion

Orthographic learning was evident on all three posttest measures in Experiment 1. Three days after reading novel words in text, second graders were able to name more quickly, identify more successfully, and reproduce more accurately the correct orthographic forms. According to the self-teaching hypothesis, the process of print-to-sound translation is the primary factor responsible for orthographic learning. However, as discussed in the introduction, an alternative explanation for the results of Experiment 1 can also be offered. Since the process of decoding novel pseudowords necessarily involves visually attending to target letters on a letter-by-letter basis, mere visual inspection rather than phonological recoding per se may have been responsible for the observed orthographic learning. Qualitative data, however, suggested that orthographic learning was attributable to *saying* rather than *seeing* the novel letter strings.

When reading aloud the printed stories, there were a small number of instances in which children mispronounced the target strings in a way that fortuitously matched one of the foils in the orthographic choice task. For example, the target ELZACH was misdecoded by five children as “EZLACH”; the latter corresponds exactly to the foil containing the transposed letters. A further two children misdecoded the target ADAZITA to match the foil AZADITA. If orthographic learning is simply the result of visual exposure, then the spelling selected in the posttest orthographic choice task should match the spelling seen in the test texts. If, on the other hand, orthographic representations depend on phonology, then choices should match the mispronunciation. Consistent with the self-teaching hypothesis, six of the seven orthographic choices were indeed the spelling that matched the child’s own mispronunciation. By way of comparison, in the 73 cases in which these two targets (ADAZITA and ELZACH) were pronounced in ways other than by transposing the two key letters (either correct or incorrect pronunciations), the (incorrect) transposed spelling foil was selected on only six occasions.

[8] The peculiar lack of orthographic redundancy in Hebrew appears to stem from a combination of several factors, including (a) a limited syllable inventory consisting almost exclusively of simple CV and CVC syllables each containing only one of five possible cardinal vowels, (b) an orthography that is primarily consonantal with vowels represented mostly in a subsidiary fashion by diacritical marks, and (c) a lexicon based (by means of a rich morphology) almost entirely on approximately 2000 triconsonantal roots with few constraints on permissible letter combinations (the notable exception being gemination of root consonants; see Berent & Shimron, 1997).

The tendency to prefer orthographic forms based on sound rather than sight was also reproduced in these same seven children's spelling data. When asked to write the target words, five out of the seven spellings again matched the transposed mispronunciation. More generally, it can be seen from Table 2 that homophonic spellings far outnumbered substitutions. Homophonic spellings differed visually from the original spellings by two (homophonic) letters, whereas the latter differed by only a single (nonhomophonic) letter especially selected for its visual similarity to a target letter. Although spellings with a letter substitution looked more like the original target, these choices were far outnumbered (16.75% versus 3.5%) by the less visually similar but more phonologically accurate homophone spellings.

Since these error analyses can only be considered suggestive, the visual attention hypothesis was directly tested in Experiment 2.

EXPERIMENT 2

In this experiment, target strings were viewed under conditions designed to minimize phonological processing. To this end, a number of procedures were adopted. These included brief exposure of targets and irrelevant concurrent vocalization in the context of a lexical decision task. The lexical decision task was adopted as it is known to induce a relatively shallow, primarily orthographic mode of processing (Seidenberg, 1985), a result that has been reliably reproduced in Hebrew-language studies of visual word recognition (Frost & Bentin, 1992; Koriat, 1985; Shimron, 1993). Brief presentation of target strings together with irrelevant concurrent articulation were designed to further reduce the likelihood of phonological recoding.

The identical posttests were administered, as in Experiment 1, 3 days after the lexical decision task. To simplify the design, only one exposure condition was used in Experiment 2. Six exposures were selected in preference to four exposures because effects were slightly stronger in the former condition and thus maximized the chances of finding an effect attributable to visual exposure alone.

Because this population of children are relatively fluent decoders (see Share & Levin, in press), some automatic phonological activation was expected in spite of the various measures aimed at deterring decoding. It was expected, therefore, that phonological processing would be substantially reduced but not eliminated. The reduced degree of phonological processing was predicted to result in significantly less orthographic learning than in Experiment 1.

Method

Sample

Twenty additional children (13 boys and 7 girls) were drawn from the same Grade 2 classes as in Experiment 1. The mean age of this group was 8:0 (*SD*, 4.6 months; range, 7:6–8:5). Reading performance (real words read in 1 min) was 72.3 (*SD*, 13.3; range, 50–106).

Materials

A total of 240 words were presented (in two separate sessions) for lexical decision. One hundred twenty real words were randomly selected from the texts used in Experiment 1. Sixty of the 120 pseudowords (nonwords) consisted of the 10 target strings from Experiment 1 each of which appeared 6 times; the other 60 pseudowords were created by changing letters in the real words.

Procedure

Each child was first introduced to the concept of real versus “made-up” words and then given several printed examples for (verbal) lexical decision. Next, it was explained that words would appear one at a time on the computer screen and the child would be asked to indicate whether the item was real or made up by pressing a button marked YES or a second button marked NO.

Presentation of the target strings on screen was preceded, on each trial, by a ready sign (two parallel lines) appearing in the centre of the screen for 1000 ms. This was then replaced by the target which was displayed for 300 ms. This exposure time was selected because it is longer than average fixation durations for skilled Israeli readers (Pollatsek, Bolozky, Well, & Rayner, 1981), but shorter than the fastest naming latencies observed in Experiment 1. Target offset was immediately followed by a letter mask consisting of a string of word-final letters (all descenders), which masked both the letter and the vowel diacritic beneath. The letter mask remained on the screen until terminated by the child’s button press. The intertrial interval (a blank screen) was 1000 ms.

Using this procedure, a practice list of 24 items was first presented to ensure that the basic lexical decision procedure was understood. Next, the child was asked to turn his/her attention to the experimenter and repeat over and over as quickly as possible the pseudoword DUBBA until asked to stop. The child was then told s/he would see the same list of 24 real and made-up words once again, but this time no button press was required. Instead, the child was required to commence repeating aloud the word DUBBA immediately the ready sign appeared and to stop vocalizing only when the target string was replaced by the letter mask. The timing of this vocalization was practised on the same list of 24 words. Once this routine was established (often after a small number of trials), the child was asked to try to make a manual YES/NO response *after* the letter mask had replaced the target string. The experimenter emphasized that only accuracy, not speed, was important.

As in Experiment 1, the children were exposed to five targets each on two separate days. Thus, in each testing session, the child made 120 lexical decisions, 30 of which were the targets (each presented six times). Care was taken to ensure that the distribution of targets (both order and proximity) matched as closely as possible the original pattern of exposure in the experimental texts. No feedback was given regarding response accuracy. Only a single child was dropped from the

TABLE 6
Posttest Orthographic Choices (Correctly Spelled Targets, Homophones, Transpositions, and Substitutions) in Experiments 1, 2, 3, and 4

Exposures = 6	Target	Homophone	Transposition	Substitution
Expt. 1 (n = 200)	78.5% (157)	15% (31)	3.5% (7)	2.5% (5)
Expt. 2 (n = 200)	50.0% (100)	20.5% (41)	11.5% (23)	18.0% (36)
Expt. 3 (n = 200)	62% (124)	23.5% (47)	4.5% (9)	10% (20)
Expt. 4 (n = 193)[a]	32.6% (63)	27.5% (53)	21.2% (41)	18.7% (36)

[a] Seven choices were lost due to experimenter error.

study owing to an inability to maintain an above-chance level of accuracy in the lexical decision task.

Posttest materials and procedures (including counterbalancing) were identical to those employed in Experiment 1, with one exception. In the case of spelling, the pronunciation of targets was directly supplied by the experimenter rather than elicited from the child.

Results

The lexical decision task with brief exposure duration and concurrent vocalization was found to be well within the capabilities of these second graders. Average accuracy of lexical decisions was 90% (*SD*, 8.5%; range, 66 to 98%).

Many children spontaneously commented that some items were coming up again and again, while several children actually supplied the correct pronunciation. Thus, phonological processing, as expected, was clearly not "eliminated" but merely reduced by the experimental procedures.

Orthographic Choice

The distribution of orthographic choices in Experiment 2, together with the parallel six-exposure data from Experiment 1, appear in Table 6.

Table 6 shows that quite a different pattern of choices emerged under conditions which reduced phonological recoding. The number of correct choices was substantially and significantly reduced (from 78.5 to 50%, $z = 5.94$, $n = 200$), with a corresponding increase (from 6 to 29.5%, $z = 6.15$, $n = 200$) in the proportion of phonologically deviant choices (transpositions and substitutions combined).

As anticipated, there was a significant degree of orthographic learning in Experiment 2. The most common choice, as in Experiment 1, was the correct target spelling. This proportion was significantly beyond the chance level of .25 ($z = 8.16$, $n = 200$). The proportion of correct choices (50.0%) also significantly exceeded the proportion of (incorrect) homophone choices (20.5%) ($z = 4.96$,

TABLE 7
Spelling Performance in Experiments 1, 2, and 3 According to an Exact Whole-Word Criterion

Exposures = 6	Target	Homophone	Nonphonological	Other	Total nonmissing
Expt. 1	53.9% (82/152)	14.5% (22/152)	47	48	199
Expt. 2	39.2% (74/189)	19.6% (37/189)	11	78	200
Expt. 3	53.3% 104/195	13.8% (27/195)	4	64	199

Note. Percentages are based on the total number of phonologically accurate reproductions.

$n = 141$). Thus, brief visual inspection with limited phonological processing appears to be sufficient to produce a significant degree of orthographic learning.

If mere visual exposure was sufficient to explain the orthographic learning evident in Experiment 1, then the pattern of results evident in Experiment 1 should have been replicated in Experiment 2. The data for orthographic choice indicate otherwise.

Naming Errors and Latencies

As in Experiment 1, each child read a total of 20 targets and 20 homophone foils. The proportion of trials lost due to equipment failure was 4.0% for targets and 2.5% for homophones. There was no significant difference in the accuracy with which targets (70.7%) and their homophone foils (70.2%) were named ($z < 1.0$). The mean of subjects' median naming latencies was 843 ms (*SD*, 365) for targets and 828 (*SD*, 375) for homophone foils. This difference was not significant ($t < 1.0$).

In short, there was no evidence of orthographic learning in the naming data in Experiment 2.

Spelling

Whole-word criterion. In Experiment 2, the target was orally dictated by the experimenter, as opposed to Experiment 1 in which the pronunciation was supplied only in the event that this could not be elicited from the child. In Experiment 1, furthermore, a child's spontaneous response was not corrected when incorrect. Comparisons between the two studies in the proportion of correct target spellings were, therefore, based on the total number of phonological accurate reproductions. These proportions are presented in Table 7.

The rate of accurate target spellings in Experiment 2 (39%) was significantly lower than the corresponding figure in Experiment 1 (53.9%) ($z = 2.71$, average $n = 170$). On the other hand, the number of fully accurate reproductions of the original target spelling (39%) was significantly above the 25% chance level ($z = 4.62$, $n = 200$) as well as significantly greater than the rate of fully homophonic spellings (19.6%), ($z = 2.95$, $n = 189$).

TABLE 8
Posttest Spelling Performance on a Per-Letter Basis (Homophonic Target Letters Only) in Experiments 1, 2, and 3

Exposures = 6	Target	Homophone	Other	Total nonmissing
Expt. 1	68.3% (263/385)	31.7% (122/385)	13	398
Expt. 2	59.5% (238/400)	40.5% (162/400)	0	400
Expt. 3	69.9% (277/396)	30.6% (121/396)	2	398

Note. "Other" responses included substitutions or omissions of critical target letters.

Per-letter scoring. As with whole-word scoring of spelling, letter-level comparisons between Experiments 2 and 1 were based on the total number of phonologically plausible graphemes (see Table 8).

As in Experiment 1, successful reproduction of homophonic target letters was significantly above the 50% chance level ($z = 3.8$, $n = 400$). There was also a significant difference between the rate of correct target versus incorrect homophonic spellings ($z = 7.6$, $n = 400$). More important, the accuracy of target letter reproduction in Experiment 2 (59.5%) was significantly lower than in Experiment 1 (68.3%) ($z = 2.56$, $n = 392$). Thus, the results for the per-letter and whole-word scoring painted a very similar picture.

The overall pattern of data for spelling accuracy (according to both whole-word and letter-based criteria) was very similar to that observed for orthographic choice with evidence of significant but reduced levels of orthographic learning.

Discussion

Experiment 2 set out to determine whether the findings in Experiment 1 can be explained by mere visual exposure. It was found that conditions designed to minimize phonological recoding significantly reduced the degree of orthographic learning across all three posttest measures. Nonetheless, the visual exposure hypothesis could still be maintained by arguing that the brevity of visual exposure (300 ms) was the source of the impaired orthographic learning and/or the fact that orthographic targets were presented without supporting context. Experiment 3 evaluated this possibility by asking children to *name* the same items presented for the same brief duration times (300 ms). Thus, comparison of the results of Experiments 2 and 3 (orthographically relevant (i.e., correct pronunciation) as opposed to orthographically irrelevant ("DUBBA") vocalization) under the same conditions (brief decontextualized exposures) provided a relatively clean test of the contribution of phonology to orthographic learning.

EXPERIMENT 3

Method

Sample

A further 20 second grade children (10 boys and 10 girls) from the same school participated in this third study (mean age, 7:11; *SD,* 4.7 months; range, 7:5–8:11). Reading performance averaged 71 words per minute (*SD,* 13.8; range, 51–92). Thus, the children in Experiment 3 closely matched the sample participating in Experiment 2 in both age (8:0) and decoding fluency (words per minute, 72).

Procedure

The identical list of words and pseudowords from Experiment 2 was used again in Experiment 3 with the same exposure and masking conditions. Instead of making a lexical decision, however, children were asked to (attempt to) pronounce aloud each item. The difference between real and made-up words was first explained, then the practice set of 24 items were presented on computer screen. Children were encouraged to attempt to decode at least part of the word even if they were unable to name the entire string in the limited time available.

Posttests were the same as in Experiment 2, with targets dictated for spelling.

Results

Decoding of Briefly Presented Targets

Despite the short exposure durations, subjects were able to generate the correct pronunciation on most occasions. Decoding accuracy (vowels ignored) averaged 71.6% (*SD,* 19%). The corresponding figure for the six-exposure condition in Experiment 1 was 85.7%.

Orthographic Choice

Responses in the orthographic choice task appear in Table 6 together with the corresponding figures from Experiments 1 and 2.

As in both Experiments 1 and 2, correct target spellings in Experiment 3 were selected at a rate significantly beyond chance ($z = 12.08$, $n = 400$) and also more often than homophone foils ($z = 5.89$, $n = 171$). Most important, the rate of target identification (62%) was significantly above the rate observed in Experiment 2 (50%) ($z = 2.42$, $n = 400$). Thus, the poorer performance in Experiment 2 cannot be explained away solely as a product of brief exposure and/or decontextualized presentation. The same presentation format with orthographically relevant as opposed to irrelevant ("DUBBA") vocalization produced a significantly higher success rate. This rate, however, was still significantly below that achieved under viewing conditions (Experiment 1) that generated significantly higher levels of decoding success ($z = 3.61$, $n = 400$).

Naming Errors and Latencies

The proportion of trials lost to equipment malfunction was 0.75% for targets and 2.0% for homophones. Target naming accuracy (for valid trials only) was 79.1% (*SD*, 13.8%) and homophone naming accuracy 75.9% (*SD*, 15.3%). This difference was significant ($t = 2.40$, $df = 19$, $p = .027$).

The mean naming speed for correct pronunciations was 782 ms (*SD*, 235) for targets and 789 ms (*SD*, 243) for homophones. This difference was not significant ($t < 1.0$) and therefore indicates that the significant difference recorded for errors is a genuine difference and does not merely reflect speed–accuracy trade-offs.

Spelling

Whole-word scoring. Spelling results for Experiment 3 appear in Table 7. It can be seen that spelling performance according to an exact whole word criterion was almost identical to the data from Experiment 1, the only difference of substance being the marked reduction in the number of phonologically inaccurate spellings. This, however, is attributable simply to the fact that target pronunciations were dictated in Experiment 3 but not in Experiment 1. Accurate target spellings were significantly above chance ($z = 9.14$, $n = 195$) and also significantly above the rate of fully homophonic spellings ($z = 11.69$, $n = 195$). The target rate was not significantly different from Experiment 1 ($z < 1.0$) but significantly above the rate attained in Experiment 2 ($z = 2.79$, average $n = 192$).

Per-letter spelling. As with the whole-word scoring, letter-based scoring closely replicated the results from Experiment 1 (see Table 8). Target spellings (69.9%) were significantly beyond chance ($z = 7.92$, $n = 396$) and also significantly above the rate of homophonic spellings ($z = 7.86$, $n = 396$). While not significantly different from the percentage of target spellings in Experiment 1 ($z < 1.0$), there was a significant difference between the rate in Experiment 2 (59.5%) and the present study (69.9%) ($z = 3.07$, average $n = 398$).

As regards letter position, there was once again no significant difference between the percentage of correctly spelled target letters in initial (67.3%) compared to post-initial (71.9%) positions ($z < 1.0$).

Discussion

The results from Experiment 3 demonstrated that under identical presentation conditions (brief, decontextualized exposure), phonological recoding of novel letter strings produced significantly greater orthographic learning on all three posttest measures than orthographically irrelevant vocalization (Experiment 2). This demonstrates a direct contribution of phonological recoding to orthographic memory, and indicates that the results of Experiment 1 cannot be attributed simply to visual exposure.

To what extent, if at all, can orthographic learning be attributed to pure visual attention? To answer this question requires an experimental manipulation in which phonological recoding is completely abolished. Owing to the extreme difficulty, if not impossibility, of totally suppressing phonological processing of legal letter strings among fluent decoders, it was decided to turn to strings of nonalphabetic symbols which offered no possibility of recoding.

In Experiment 4, second graders viewed strings of familiar nonalphabetic symbols (e.g., ? + * $, etc.) which matched both the length and visual complexity of the target words used in Experiments 1 to 3. To ensure that the individual symbols were highly familiar to children at this age, it was decided to use a combination of common logographic symbols such as punctuation marks (e.g., ? !), arithmetic operators (e.g., = +), geometric symbols (△ □), and several other miscellaneous symbols (e.g., $ * #), all of which are fairly common everyday symbols to Israeli children. Since letter by letter decoding was considered to involve both item (letter) level and string (word) level processing, two experimental tasks (letter search and string length judgement) were adopted to ensure that both types of processing took place.

EXPERIMENT 4

Method

Subjects

A fourth group of 20 second grade children was randomly drawn from the same school. This group included 10 boys and 10 girls with a mean age of 8:0 (*SD*, 3.8 months; range, 7:6–8:8). Mean number of words read in 1 min averaged 67.7 (*SD*, 20.34; range, 19–96).

Materials and Procedure

First, an “alphabet” was created consisting of 20 nonalphabetic symbols (target strings in Experiments 1 to 3 contained 20 of the 22 letters of the Hebrew alphabet). These 20 characters were then randomly paired with the original 20 letters. Ten target strings were then generated simply by replacing the original target letters with the corresponding symbols. For example the four-letter string KUTA became X-$△. Thus, string length and symbol variety were identical to the original target strings.

As in Experiments 1–3, children were exposed to only five different target strings at one sitting. Each string appeared six times in random order on a single printed page divided into three columns each of 10 words. The size of individual symbols was similar to the original letter size. Since this task was not expected to be easy, it was decided to present only target strings in this study and no others.

Since neither spelling nor naming is possible with nonpronounceable strings, only orthographic choice was administered at posttest 3 days later.

Procedure

Children were presented with a printed page containing 30 symbol strings and required to perform two tasks with each string on the sheet. First, they were to check if the string contained a particular character (+ for the first list, $ for the second list) and circle this particular character (40% of the strings contained a target character). Next, they were asked to count the number of symbols in each string and circle the entire string if it contained exactly 5 symbols (40% of all strings in both lists).

Posttest orthographic choice was also designed to mimic the original set of alternatives. The original four choices were simply "transcribed" or "encoded" into the symbol alphabet. There was one exception to this; for the substitution foil, the symbol judged most similar visually was used rather than the corresponding symbol from the symbol alphabet. Since there was no homophony in this symbol set, the "homophonic foil" essentially represented a second "substitution" foil.

Posttest procedure was the same as in Experiments 1–3.

Results

The symbol search and string length judgment tasks posed little difficulty for this group. There was only a total of 20 errors across the entire sample, representing an error rate of 1.7% (range, 0–8.3%; mode = 0). The pattern of posttest choices is summarized in Table 6.

In contrast to the outcomes of the previous experiments using letter strings, differences between the four alternatives were not large. A chi-square test, however, indicated that choices were not evenly distributed across the four alternatives ($\chi^2 = 9.18$, $df = 3$, $p < .05$). Correct targets were selected on 32.6% of occasions. This compares to a selection rate of 78.5% for the corresponding 6-exposure condition in Experiment 1. Although not significantly beyond the selection rate for the second most common choice ("homophone" foils) ($z = 1.57$, n.s.), correct target choices were selected at a rate significantly beyond the 25% chance level ($z = 2.45$, $p < .05$) indicating a nonchance degree of visual memory.

Although significantly beyond chance, the magnitude of this visual exposure effect was very small—only 7.6% higher than would be expected by chance alone (32.6–25%). This compares to an effect size of 52.5% (78.5–25%) when target strings were decoded in meaningful context. In other words, the contribution of visual exposure alone to the results obtained in Experiment 1, probably represents only a small proportion of the overall learning effect observed in this study.

GENERAL DISCUSSION

The first experiment established that second grade readers spontaneously apply their knowledge of symbol–sound relationships to novel letter strings encountered in text. They do not simply skip or guess unfamiliar items, at least in the case of a regular orthography such as pointed Hebrew. Thus, working knowledge of letter–sound relationships as evident in the ability to correctly pronounce lists of pseudowords is not merely "inert" but applied on-line when reading aloud and understanding text. Since all target strings were pseudowords, neither prior knowledge nor contextual guessing can account for the observed orthographic learning.

Three days after reading the test texts, target spellings were identified more often, named more quickly and spelled more accurately than alternate homophonic spellings. As there were relatively small differences between the outcomes of the four-exposure and six-exposure conditions, it appears that four (or perhaps fewer) exposures are sufficient for significant orthographic learning (cf. Ehri & Saltmarsh, 1995; Manis, 1985; Reitsma, 1983, 1989). The present study, therefore, replicates the basic finding regarding rapid orthographic learning first reported in the developmental literature by Reitsma (1983) and, furthermore, extends this finding to unassisted oral reading of text. It remains to be investigated precisely how many exposures, under which conditions, and over what period of time can produce significant orthographic learning, although the author eschews the view that such learning is an all-or-none process. It may be more profitable to consider orthographic learning as a progressive (nonmonotonic) strengthening of connections (Ehri, 1992; Perfetti, 1992; Plaut, McClelland, Seidenberg, & Patterson, 1996). Moreover, the precise nature of the pattern of processing taking place during encounters with novel words (exhaustive letter-by-letter decoding versus holistic guessing based on an initial letter and prior context) may well be more decisive as regards orthographic memory than the simple tally of exposures.

The evidence of rapid orthographic learning among such young readers explains why a number of older "dual-route" studies reported that even beginning readers appear to be relying on "direct" visual access rather than "indirect" grapheme-to-phoneme translation when identifying *high-frequency* words (Barron & Baron, 1977; Bryant & Bradley, 1983; Condry, McMahon-Rideout, & Levy, 1979; Kimura & Bryant, 1983; Rader, 1975). The present data also furnish additional support for an *item-based* as opposed to *stage-based* view of phonological recoding whereby the process of word recognition depends primarily on the frequency to which a child has been exposed to a particular word (together with the nature and success of item identification), rather than on an omnibus transition from one developmental stage ("visual" or "phonological") to another (see Share, 1995).

But is this impressive orthographic learning attributable to phonological recoding per se or simply to the experience of seeing a word repeatedly in print? Some qualitative observations in Experiment 1 suggested that orthographic learning depends on what a child says rather than on what they see. Children tended to identify and spell words in a way that matched their own *mis*pronunciations. In addition, overall choices of spelling foils that looked more like the original targets were far outnumbered by foils that looked less like the original target but sounded correct.

Experiment 2 directly examined the visual-exposure account by presenting target words under conditions designed to minimize phonological recoding. It was clear, however, that phonological recoding was not eliminated, only reduced. Evidence of spontaneous naming of targets by some subjects in this second study, together with the fact that children in Experiment 3 were able to overtly pronounce most targets successfully within the same brief time indicated, as anticipated, that some degree of automatic phonological activation (and/or covert articulation) was probably taking place among significant numbers of children in Experiment 2. This "irrepressibility" of phonology is consistent with the findings from fluent adult readers (e.g., Perfetti & Bell, 1991; Perfetti, Bell, & Delaney, 1988; Van Orden, 1987; Van Orden, Johnston, & Hale, 1988) showing that phonological information is activated automatically almost immediately following presentation of a word.

As predicted, reduced phonological processing in Experiment 2 led to attenuated orthographic learning. Experiment 3 went on to show that this reduction in orthographic learning was not attributable to either brief visual exposure or to the loss of contextual support. Comparison of Experiments 2 and 3 in which vocalization either did or did not correspond to the target spelling (with viewing conditions held constant) provided direct evidence for the contribution of phonological recoding to the acquisition of word-specific orthographic information. It can therefore be concluded that phonological recoding enables the young reader to acquire word-specific orthographic information as proposed by the self-teaching hypothesis.

The unique contribution of visual exposure to orthographic learning was directly assessed in Experiment 4. Using strings of nonalphabetic characters comparable to the earlier target letter strings both in visual familiarity and complexity, it was found that recognition memory for these strings was only slightly beyond chance. It might be argued that this result underestimates the potential contribution of visual-orthographic factors because such nonalphabetic strings have neither familiar orthographic structure nor redundancy of the type that might be expected to facilitate visual memory for orthographically legal strings. While this argument would be potentially true had this study been carried out in English, the minimal orthographic redundancy of Hebrew's consonantal root-based orthography (see Footnote 3) renders this an unlikely confound in the case of Hebrew. On the other hand, it must be conceded that these alphabetic symbols, although familiar everyday forms for this population, may well be less familiar than printed letters. Thus, it cannot be ruled out that Experiment 4 underestimates the role of purely visual-orthographic factors in orthographic learning. However, it seems doubtful that purely visual attention accounts for more than a slender portion of the variance in orthographic learning evident in Experiments 1 and 3. Other studies have also demonstrated the extraordinary difficulty involved in memorizing strings of nonalphabetic symbols containing common visual elements (e.g., Ehri & Wilce, 1987; Jorm, 1981).

The failure in Experiment 4 to obtain evidence of appreciable nonphonological visually based learning is also instructive as regards general theories of printed word learning in alphabetic orthographies. Although individual symbols in these strings are eminently nameable, they are not recodable in a way that *bonds together* or *amalgamates* letters into a consolidated unit as proposed by Ehri (1978, 1987, 1992). Letter identity and letter order—the foundation of orthographic knowledge—simply make no sense unless linked to a specific pronunciation, one furthermore that is fully analyzed at the phonemic level. No other information source specifies why particular letters appear in a particular order for the obvious reason that alphabetic orthographies are first and foremost phonemic transciptions. Unlinked to a fully specified pronunciation, letters appear as a near-senseless jumble, as was probably the case in Experiment 4.[9] These considerations point to at least one reason why phonemic awareness may be so critical in learning to read an alphabetic orthography. Only when a child is aware of all the phonemes in a word's pronunciation (their identity and position) will there exist a template/substrate onto which to map each and every element in the orthographic string. This lack of a well-specified *grapheme-level* (as opposed to string-level) representation, to which items in the string can be mapped, is probably the reason why learning in Experiment 4 was so meager. If this is the correct interpretation of this final experiment, it constitutes strong support for Ehri's view that spellings can only be memorized when linked to phonemes detected in pronunciations (Ehri, 1992). The process of letter-by-letter decoding *and blending* (amalgamating) spoken segments into an integrated unit, or in short, bottom-up phonological recoding, may be ideally adapted for the mapping of orthographic detail (Venezky, 1970). Spelling, of course, is another such process which obliges the explicit processing of letter order and letter identity.

Overall, the strength of orthographic learning observed in this investigation tended to mirror the levels of phonological processing from least (Experiment 2) to most (Experiment 1). The self-teaching hypothesis, however, does not propose that phonological recoding alone determines orthographic learning. Over and above decoding ability, there appear to be important differences between readers in their ability to remember word-specific information (Barker et al., 1992; Cunningham & Stanovich, 1990a, 1993; Olson et al., 1990, 1994; Stanovich et al., 1991). The volume of exposure to print is obviously another key factor (Anderson, Wilson, & Fielding, 1988; Cipielewski & Stanovich, 1992; Echols, West, Stanovich, & Zehr, 1996). Yet another source of individual differences in orthographic learning may be meaning (Plaut et al., 1996). A first approximation regarding the contribution of meaning and context can be gauged by comparing the effect sizes in Experiment 1 (decoding in context) with Experiment 3 (decoding without meaningful context), although, of course, this comparison is confounded by both (large) exposure time and (small) decoding rate differences.

[9] Even when viewed nonphonologically, letter strings may not be *entirely* "senseless jumbles" owing to the existence (in varying degrees across orthographies) of orthographic redundancy.

While the spelling data were virtually identical, the orthographic choice data declined from 78.5 to 62% thereby preserving most of the effect. Thus meaning does not appear to be a major factor in learning word-specific spellings. The issue of sources of individual differences in orthographic learning is clearly an issue of major importance for future research.

In view of important differences between Hebrew and English orthography in orthography redundancy, the representation of consonants versus vowels, morphological density, word shape, and letter architecture (see Share & Levin, in press; Shimron & Sivan, 1994), it is well to ask to what extent the present results may be language-dependent. Like other shallow orthographies such as German or Italian, the near-perfect letter–sound correspondence in pointed Hebrew makes decoding a relatively straightforward task by comparison to English. In view of the relative ease with which novel letter strings can be identified via phonological recoding in Hebrew, it might be argued that the present findings may have limited applicability to English, or, seen from the non-Anglophone perspective, the peculiarities of English orthography may render it the exception to the general rule of regular/shallow orthographies in which decoding is relatively straightforward. The frequent lament regarding English spelling irregularity, however, is ill-founded because irregularity is confined largely to the vowels which have a marginal role in word recognition (Adams, 1990; Shimron, 1993); even highly irregular English words may have *sufficient* letter–sound regularity to be successfully identified *when encountered for the first time in natural text* (see Share, 1995). In any case, the validity of the claim that English is too irregular to be efficiently decoded, together with the generality of the self-teaching phenomenon across languages and orthographies, must be put to empirical test. The claim to be tested is that any script which is functionally decodable *in context*, and sufficiently encapsulated to permit identification of specific lexical items (i.e., minimal homophony and homography), should permit functional self-teaching.

To what extent do current connectionist models incorporate self-teaching? Although space limitations preclude discussion of several aspects of PDP modeling relevant to this question, one point is especially pertinent. This point relates to the fact that the self-teaching idea was strongly motivated by the observation that young readers are continually encountering novel letter strings for which neither contextual guessing nor direct instruction (by teachers or others supplying a word's identity) is likely to be effectual (see discussion in Share, 1995; Share & Stanovich, 1995). Indeed, a cardinal assumption about self-teaching is that the ability to derive the pronunciation of a novel printed word *independently* on the basis of sublexical correspondences between orthography and phonology (however these may be represented) constitutes the only effective means of acquiring the orthographic knowledge on which skilled word recognition depends. This implies that the overwhelming majority of orthographic representations are in fact self-taught. While recent PDP simulations by the Seidenberg/McClelland/Plaut group have demonstrated successful identification (pronunciation) of novel letter strings (both words and nonwords), performance has been examined only after a massive training regimen involving between 300 and 3000 learning "epochs," each of which requires the correct pronunciation of some 3000 printed words to be directly input to the network (Plaut et al., 1996; Seidenberg, Plaut, Petersen, McClelland, & McRae, 1994). In the absence of these externally supplied pronunciations, the system has no way of generating the target pronunciations required to boot the learning algorithm (see Skoyles, 1988). In view of the avalanche of unfamiliar orthographic strings continually being encountered in children's printed texts (Carroll et al., 1971; Firth, 1972; Rodenborn & Washburn, 1974), and the futility of large-scale direct instruction (Chall, 1987; Nagy & Herman, 1987), the training phase integral to these PDP models is both psychologically and pedagogically implausible. It is worth remarking that neither programs of direct vocabulary instruction (Calfee & Drum, 1986; Nagy & Herman, 1987) nor item-by-item teaching of characters in logo-syllabic scripts such as Chinese characters or Japanese Kanji ever aim to impart more than a few hundred items *per year* (Mason, Anderson, Omura, Uchida, & Imai, 1989; Taylor & Taylor, 1983). Current PDP models of the Seidenberg/McClelland/Plaut variety therefore fail to address the quintessential problem of reading acquisition—*independent generation of target pronunciations for novel letter strings.* However, at least one group of researchers (Zorzi, Houghton, & Butterworth (1998) has recognized this problem and set out to develop a connectionist model which can successfully decode new items after exposure to only a plausibly small set of words. These authors trained a two-layer network consisting of position-coded letter and phoneme units (but no hidden units) on a set of only 86 words (Glushko's regular and exception words). After only 80 learning epochs, this simple network achieved perfect performance on the trained set of 86 real words and, more importantly, 90% success on a set of nonwords derived from the 86 real words. Although preliminary,[10] this work appears to be a valuable first step toward developing more developmentally plausible connectionist models which do not depend on massive but unrealistic direct instruction and which open up the possibility of implementing the self-teaching idea within the PDP framework.

APPENDIX

In the middle of Australia is the hottest town in the world. This town is called Akunia and it's right in the middle of the desert. In Akunia, the temperature can reach 60 degrees. It's so hot that even the flies drop dead and the rubber tires on the cars start to melt. You can even fry an egg on the roof of your car.

The houses in Akunia are under the ground, far away from the heat of the sun. The people also dig for gold deep under the ground. In Akunia, they drink lots

[10] It would be premature to consider these data conclusive because there was no evaluation of the network's ability to "pronounce" either words or nonwords other than those in (or derived directly from) the initial training set. To establish developmental plausibility of this system it would also be necessary to demonstrate generalization when the training set itself approximated the corpus of words which beginning readers are likely to be taught and/or exposed to.

of beer to stay cool. They drink beer in the morning, in the afternoon, and in the evening. The beer in Akunia is very strong. If you're not used to drinking beer you'd better watch out!

Would you like to live in Akunia?

Comprehension Questions

1. Why is the town in the story special?
2. Where is this town?
3. What strange things happen in this town when it gets very hot?
4. Where are the houses in this town?
5. What's special about the beer in the story?

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