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Converging evidence for the concept of orthographic processing

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Abstract. Six different measures of orthographic processing (three different letter string choice tasks, two orthographic choice tasks, and a homophone choice task) were administered to thirty-nine children who had also been administered the word recognition subtest of the Metropolitan Achievement Test and a comprehensive battery of tasks assessing phonological processing skill (four measures of phonological sensitivity, nonword repetition, and pseudoword reading). The six orthographic tasks displayed moderate convergence – forming one reasonably coherent factor. Hierarchical regression analyses indicated that a composite measure of orthographic processing skill predicted variance in word recognition after variance accounted for by the phonological processing measures had been partialed out. A measure of print exposure predicted variance in orthographic processing after the variance in phonological processing had been partialed out.

Keywords: Orthographic processing, Phonological processing, Reading acquisition, Word recognition

Introduction

A voluminous amount of empirical research supports the conclusion that phonological processing abilities are crucially related to reading acquisition (e.g., Brady & Shankweiler 1991; Frost 1998; Gough, Ehri & Treiman 1992; Liberman & Liberman 1990; Perfetti 1985, 1995; Share & Stanovich 1995; Siegel & Ryan 1988; Snowling 1995, 1996; Stanovich 1986, 1988). Despite the importance of phonological variables in explaining variance in the acquisition of word recognition skill, it is possible that another class of factors is involved. Although the correlations between phonological processing skill and word recognition ability are quite high, they still leave some reliable word recognition variance unaccounted for. In addition, some investigators have argued that the development of a minimal level of phonological sensitivity is a necessary but not sufficient condition for the development of efficient word recognition processes (Juel, Griffith & Gough 1986; Tunmer & Nesdale 1985).

As a result of these theoretical speculations, attention has centered on orthographic processing abilities as a potential second source of variance in word recognition ability (see Berninger 1994; Stanovich & West 1989). However, isolating individual differences in orthographic processing is problematic because there is little doubt that the development of orthographic processing skill must be somewhat dependent on phonological processing abilities (Barron 1986; Ehri 1984, 1995, 1997; Juel et al. 1986; Share 1995; Stanovich & West 1989). The critical question for research is whether the development of the orthographic lexicon is entirely parasitic on the operation of phonological processes. The problem is that the decoding skills enabled by phonological abilities facilitate the building of the orthographic lexicon via processes such as self-teaching (see Share 1995 for a detailed discussion). Efficient phonological coding also makes for a pleasurable reading process and thus may increase the degree of self exposure to print – thus further building the orthographic lexicon. If the quality of the orthographic lexicon was entirely due to such processes, then orthographic processing per se would not be a source of independent variance. This conjecture yields the prediction that orthographic processing ability should not account for variance in word recognition skill, once the influence of phonological skill has been removed.

There have, however, been some suggestive findings that have contradicted this prediction. Specifically, there have been indications that even after the considerable variance associated with phonological processing has been partialed out, orthographic processing skills explain significant additional variance in reading and spelling ability (Barker, Torgesen & Wagner 1992; Cunningham & Stanovich 1990, 1993; Stanovich & West 1989). In the present study, we attempt to add to this suggestive yet scattered evidence by examining the most comprehensive set of orthographic tasks yet to be empirically investigated.

An additional issue that we were able to investigate in this multivariate study was the question of the convergent validity of measures of orthographic processing. It appears timely to address this question because the increasing theoretical attention being given to orthographic processing has led to increased emphasis on the conceptual complexities surrounding the construct (see Berninger 1994, 1995; Vellutino, Scanlon & Tanzman 1994, for extensive and insightful discussions). The theoretical issues will only be resolved when we have better knowledge of the empirical relationships involving the wide range of tasks that have been put forth as partial operational definitions of the concept of orthographic processing. Although there has been intense interest in the covariance structures of various phonological tasks (Hoien et al. 1995; McBride-Chang 1995; McBride-Chang et al. 1997;

Stahl & Murray 1994; Stanovich et al. 1984; Wagner et al. 1993; Wagner et al. 1994; Wagner et al. 1997; Yopp 1988), there has been less work on the relationships among the various tasks that are termed measures of orthographic processing. In this study, we focused on the issue of convergent and predictive validity using a broader range of orthographic tasks than previously examined.

Method

Subjects

Sixty-two children (34 males and 28 females) with a mean age of 7 years, 3 months (range = 6 years, 1 month to 8 years, 2 months) were recruited from three first grade classrooms in a predominantly lower-class elementary school in a rural Northwest area. A battery of tasks was administered in January and February of the school year. Children identified for special education were not included in the study. Two subjects moved from the area in the middle of the first phase of the study. The following year, forty-seven second grade children (26 males and 21 females) with a mean age of 8 years, 5 months (range = 7 years, 8 month to 9 years, 4 months) remained from the previous sample, and a battery of tasks was administered in April and May of the school year. By the third year of our study, thirty-nine children (20 males and 19 females) with a mean age of 9 years, 5 months (range = 8 years, 8 months to 10 years, 4 months) remained in our sample, and a battery of tasks was administered in May and June of the school year. All of the analyses reported are based upon the final third grade sample (N = 39).

Tasks and procedure – First grade

The following battery of phonological processing tasks was administered during the first grade.

Phoneme deletion – onset. The first phoneme deletion task had three practice and ten experimental trials. This type of task was originally employed by Bruce (1964) and Calfee, Chapman and Venezky (1972). The subjects were instructed to listen closely to a word, after which the experimenter described how the first sound could be taken off and a different word would be left. The subjects were given examples and instructed to report what word was left after they took off the first sound. This first sound was always a consonant. The practice words were: cat, tend, cape; the experimental words were: pink, man, nice, win, bus, pitch, told, car, hit, pout. This task was individually

Table 1. Descriptive statistics

Task	Mean	Standard deviation	Skewness
First grade			
Phoneme deletion-onset (max = 10)	6.44	4.09	–0.56
Phoneme deletion-initial blend (max = 10)	4.56	3.39	0.19
Phoneme deletion-final blend (max = 10)	5.13	3.61	–0.10
Phoneme oddity (max = 10)	10.03	4.89	–0.21
Pseudoword reading (max = 15)	6.82	4.82	0.25
Second grade			
Letter string choice 1 (max = 16)	10.10	1.91	–0.63
Letter string choice 2 (max = 17)	10.87	1.81	–0.43
Letter string choice 3 (max = 18)	12.23	2.08	0.03
Orthographic choice (max = 23)	17.87	3.72	–0.29
Homophone choice (max = 17)	12.51	2.45	0.26
PIAT spelling (max = 50)	22.26	6.33	0.35
Nonword repetition (max = 32)	20.56	4.35	–0.73
Third grade			
Title recognition test	0.19	0.18	0.88
Pseudoword reading (max = 10)	7.23	2.32	–0.91
MAT word recognition	589.13	36.03	0.19

administered and took approximately 5 minutes. The score on the task was the number correct out of ten. Table 1 displays the descriptive data on all experimental tasks. The split-half reliability (Spearman-Brown corrected) was 0.98.

Phoneme deletion – initial blend. This task required the children to delete the initial phoneme from a series of ten beginning consonant blend words and pronounce the embedded word or word-like segment that remained. The experimenter instructed the children to listen closely to the target word and then to remove the initial sound. The experimenter indicated that this task was just like the previous one and again provided an example, “Listen to the word ‘block’. If you take away the /b/ sound, what word is left?” The children were then told if they were correct or incorrect and why. Following two more practice trials, the ten experimental words were given (stop, trick, smart, crib, strip, spark, globe, spot, smack, and snipe). This task was individually administered and took approximately 5 minutes. The score on the task was the number correct out of ten. The split-half reliability (Spearman-Brown corrected) was 0.91.

Phoneme deletion – final blend. This task required the children to delete the final phoneme from a series of ten final consonant blend words and provide the remaining sounds. Again, the experimenter told the children that the task was like the previous one except that this time they were to delete the final sound from a word. The experimenter said "Listen to the word 'park'. If you take away the /k/ sound, what is left?" The children were then told if they were correct or incorrect and why. Following two more practice trials, the ten experimental words were presented (drift, lard, best, lift, crust, spend, cork, just, craft, and blast). This task was individually administered and took approximately 5 minutes. The score on the task was the number correct out of ten. The split-half reliability (Spearman-Brown corrected) was 0.88.

Phoneme oddity. The fourth measure of phonological awareness was a phonological oddity rhyme task developed by Bradley and Bryant (1978). Initially, a memory task was administered to insure the child was capable of retaining three words in memory. All of the subjects were capable of retaining three words in memory. The children were then instructed to listen closely to three words, two of which contained a common sound that the third word lacked (e.g., sun, sock, rag). Their task was to identify the "odd word" or one that sounded different in that set. Three practice trials preceded three sets of experimental trials. The first set contained six trials that compared initial sounds of words; the second set contained six trials that compared final sounds; and the third set contained six trials that compared medial sounds of words. At the beginning of each set, the children were told where they should listen for the odd sound, (i.e., initial, medial, or final sound). This task was individually administered and took approximately 5 minutes. The score on the task was the number correct out of ten. The split-half reliability (Spearman-Brown corrected) was 0.79.

Pseudoword reading. We employed a pseudoword reading task to measure children's decoding ability. A pseudoword is a nonword that conforms to the orthographic and phonological structure of English. This task assesses children's ability to apply spelling-to-sound correspondence rules or analogies, since a visual or "whole-word" strategy will not be effective with pseudowords. The experimental stimuli employed were 15 pseudowords (lat, wuck, mip, pish, jun, hreep, fob, rill, luss, trink, bope, sut, zock, bink, nust). Initially, we provided three pseudowords (ged, dar, and cath). The children were shown the practice pseudowords on 3 × 5 index cards and instructed they were not real words but could be sounded out. Their task was to try to sound out each word and say its name. Guidance in sounding out the practice pseudowords was provided. The task lasted approximately 10 minutes. The score on the pseudoword task was the number correct out of fifteen. The split-half reliability (Spearman-Brown corrected) was 0.78.

Tasks and procedure – second grade

In the second grade, the students completed a battery of tasks designed to assess orthographic coding skill. We chose six commonly employed tasks of orthographic processing. Additionally, the children were administered one measure of phonological processing – a nonword repetition task.

Letter string choice 1. This task was taken from the work of Treiman (1993; Cassar & Treiman 1997). Sixteen pairs of three to seven letter strings were presented to the children on a sheet of paper. The experimenter told the children "Place a blank sheet of paper under row number one. You should see two word pairs that look like this (beff and ffeb were printed on the blackboard). I'd like you to circle the one word that looks most like it could be a real word. If you don't know the answer I'd like you to guess." After the children had done so, the experimenter instructed the children to slide the paper under the second word pair and once again to circle the letter string that most resembled a real word, and so on through the remainder of the task. The word pairs were: beff-ffeb, ddaled-dalled, yikk-yinn, vadding-vayying, nuck-ckun, ckader-dacker, vadd-vaad, muun-munt, ist-iit, moyi-moil, aut-awt, bey-bei, dau-daw, gri-gry, chim-chym, and yb-ib. This task was group administered and lasted approximately 5 minutes. The score on the task was the number correct out of sixteen. The split-half reliability (Spearman-Brown corrected) was 0.26.

Letter string choice 2. This task was group administered following the same procedures that were used in the first letter string choice task (letter string choice 1) (i.e., the children were asked to circle the string of letters that looks most like it could be a real word). Seventeen pairs of four letter strings employed in previous studies (see Siegel, Share & Geva 1995; Stanovich & Siegel 1994) were presented to the children on a sheet of paper: filv-filk, tolz-tolb, powl-lowp, dlun-lund, fant-tanf, miln-milg, togd-togn, wolg-wolt, moke-moje, jofy-fojy, cnif-crif, bnad-blad, hift-hifl, gwup-gnup, nitl-nilt, clid-cdil, and vism-visn. This task lasted approximately 5 minutes. The score on the task was the number correct out of seventeen. The split-half reliability (Spearman-Brown corrected) was 0.02. The reliabilities of the letter string

Table 2. Intercorrelations among the primary variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Pseudoword reading (1st)														
2. Phoneme deletion-onset	0.39													
3. Phoneme deletion-inital blend	0.65	0.60												
4. Phoneme deletion-final blend	0.54	0.70	0.56											
5. Phoneme oddity	0.57	0.48	0.32	0.63										
6. Nonword repetition	0.56	0.45	0.48	0.55	0.45									
7. Letter string choice 1	0.54	0.31	0.25	0.23	0.56	0.48								
8. Letter string choice 2	0.34	0.42	0.16	0.37	0.54	0.34	0.26							
9. Letter string choice 3	0.58	0.25	0.22	0.45	0.68	0.42	0.45	0.70						
10. Orthographic choice	0.25	0.28	0.05	0.25	0.37	0.32	0.32	0.52	0.42					
11. Homophone choice	0.29	0.38	0.15	0.34	0.50	0.27	0.40	0.66	0.54	0.47				
12. PIAT spelling	0.69	0.57	0.51	0.55	0.57	0.69	0.56	0.62	0.61	0.49	0.73			
13. Title recognition test	0.55	0.50	0.40	0.55	0.72	0.43	0.44	0.50	0.58	0.44	0.63	0.63		
14. Pseudoword reading (3rd)	0.53	0.44	0.43	0.31	0.46	0.25	0.44	0.26	0.39	0.40	0.30	0.58	0.48	
15. MAT word recognition	0.45	0.55	0.35	0.55	0.72	0.45	0.52	0.45	0.51	0.55	0.54	0.68	0.58	0.71

Correlations greater than 0.32 in absolute value are significant at the 0.05 level (two-tailed).

choice task 1 and task 2 are obviously startlingly and inexplicably low based on previous research with these tasks. For example, letter string choice 1 displayed a reliability of 0.67 in a previous study (Cunningham & Stanovich 1993). We believe this is a statistical anomaly for the following reasons. First, as apparent from Table 2, both tasks displayed significant correlations with many other variables. Secondly, when additional analyses were run using the two halves of letter string choice 1 and letter string choice 2, they displayed consistently positive correlations with other variables in the study – correlations larger than those between the two halves themselves.

Letter string choice 3. The procedure and instructions for this task were the same as in all previous letter string choice tasks (i.e., the children were asked to circle the string of letters that looks most like it could be a real word). Eighteen pairs of four to five letter strings employed in previous studies (see Siegel, Share & Geva 1995; Stanovich & Siegel 1994) were presented to the children on a sheet of paper. However, unlike in letter string choice 2, on this task the stimulus pairs had fairly similar pronunciations. The stimulus pairs were: dake-dayk, vosst-vost, sckap-skap, boap-bowp, wibz-wibs, jeex-jeeks, fage-fajy, qoast-quost, lape-laip, holp-hollp, vose-voaz, ffim-phim, booce-buice, furb-firb, nurm-nerm, hoin-hoyn, toove-touve, and lerst-lurst. This task lasted approximately 5 minutes. The score on this task was the number correct out of eighteen. The split-half reliability (Spearman-Brown corrected) was 0.51.

Orthographic choice. The orthographic choice task was adapted from the work of Olson and colleagues (e.g., Olson, Forsberg, Wise & Rack 1994; Olson, Wise, Conners, Rack & Fulker 1989). The students viewed pairs of letter strings that sounded alike (e.g., rain-rane) and were asked to indicate which one was spelled correctly. Because the two strings sound the same when decoded, differences in phonological decoding ability cannot be the sole cause of performance differences on this task (indeed, it is possible that it is an interfering factor). Although students might still use phonological recoding to determine into what word the two strings map, the task requires that lexical representation be examined. Thus, the task to some extent reflects the accessibility and quality of the orthographic entries in the lexicon. Twenty-three pairs of phonologically similar letter strings were presented to the children on a sheet of paper. Each pair contained one word and one non-word. The word pairs were: take-taik, gote-goat, sleap-sleep, hole-hoal, rume-room, snoe-snow, face-fase, hert-hurt, sheep-sheap, smoak-smoke, bowl-boal, cloun-clown, word-wurd, cote-coat, rain-rane, stoar-store, lurn-learn, nice-nise, scair-scare, skate-skait, true-trew, streem-stream, and wize-wise. The experimenter told the children that each pair of letter strings contained one word that was spelled correctly and one that was spelled incorrectly. They were then instructed to circle the correctly spelled word. This task was group administered and took approximately five minutes to complete. The score on the task was the number correct out of twenty-three. The split-half reliability (Spearman-Brown corrected) was 0.84.

Homophone choice. This task was adapted from Stanovich and West (1989). Seventeen pairs of phonologically identical, but orthographically different words were presented to the children on a sheet of paper. The subjects were instructed to listen carefully to the experimenter, who would be reading short sentences (four to six words in length) to them. Each sentence was in the form of a question (e.g., which is a part of the body?) that the children were instructed to answer by circling which of the two words was spelled correctly, according to the way it was used in the sentence (e.g., feet). Each item was preceded by a question in this manner. The children received three practice trials (meet-meat, feat-feet, and dew-due) before the seventeen experimental trials were administered. The experimental word pairs were: rose-rows, tail-tale, ate-eight, cents-sense, bare-bear, ant-aunt, flour-flower, one-won, sail-sale, hair-hare, blew-blue, deer-dear, hall-haul, pair-pear, stake-steak, week-weak, and brake-break. This task took approximately 5 minutes to complete. The score on the task was the number correct out of seventeen. The split-half reliability (Spearman-Brown corrected) was 0.62.

Peabody Individual Achievement Test – Spelling Subtest (PIAT). Fifty words (plates 13 through 62) taken from the Peabody Individual Achievement Test (Dunn & Markwardt 1970) were used as stimuli: see, gone, can, big, man, good, cow, has, when, time, garden, girls, brother, windows, last, stamps, youth, zone, sugar, thumb, motel, cloudy, dollar, towel, sentence, bicycle, science, nerve, dangerous, holiday, political, succeed, vegetable, marriage, experience, disease, pamphlet, business, excellence, committee, citrus, syndicate, installation, secretary, nuisance, restaurant, supplementary, temporarily, pretentious, and inaugurate. This task was individually administered in approximately 10 minutes using standardized procedures and instructions. The experimenter pronounced each word, used it in a sentence, then pronounced the word again. For each target word (e.g., cow) the subject viewed four alternatives, three of which were incorrect (e.g., cou, cau, caw). The children indicated their choice on a sheet of paper numbered one through fifty. Because the alternatives are minimally different (e.g., time, teim, tihm, and tiem), performance is facilitated if the student has an accurate and complete orthographic representation of the stimulus stored in memory.

The score on the task was the number correct out of fifty (sample mean = 21.98, SD = 6.26, range = 9–35). The split-half reliability (Spearman-Brown corrected) was 0.88.

Nonword repetition. A test of nonword repetition (Gathercole & Baddeley 1993) tapping phonological short-term memory was administered. In this task, the child was required to immediately repeat a nonword spoken by the experimenter on a prerecorded audio tape. Thirty-two words, varying in length from one to four syllables, were prerecorded and presented to the children at the rate of one syllable every three seconds. If the child did not respond within two seconds, the tape presenting the words was turned off until the child spoke. The experimenter instructed the children as follows: "I am going to play a tape and you will hear a voice saying a made-up word on the tape. They aren't real words, rather they are silly sounding; nothing you've heard before. I want you to listen closely and repeat the silly word right after you hear it, exactly the way she says it." The experimenter recorded the child's response on tape and on a sheet of paper. Two practice trials (bift and prindle) preceded the thirty-two experimental trials. Feedback was given to the child regarding their performance on the practice trials. The experimental words consisted of two-, three-, and four-syllable nonwords, containing single consonants and consonant clusters. The stimuli were: sep, nape, tull, thip, hond, grall, smip, clird; pennel, rubid, diller, bannow, hampent, glistow, sladding, tafflest; commerine, barrazon, doppelate, thickery, frescovent, trumpetine, brasterer, skiticult; penneriful, loddenapish, fenneriser, woogalamic, blonterstaping, stopograttic, contramponist, and empliforvent. This task was individually administered and lasted approximately 10 minutes. Each child received two different scores on this task: the total number of correct syllables out of eighty and the total number of correct items out of thirty-two. Only the total number of correct words was used in the analyses reported here. The split-half reliability (Spearman-Brown corrected) of the total number of words was 0.84.

Tasks and procedure – third grade

Measures of print exposure, pseudoword reading, and word recognition ability were administered in May/June of the children's third grade year.

Print exposure: Title Recognition Test (TRT). The TRT was designed to measure children's literacy environment. The version of the TRT employed in the present investigation was similar to the children's measure used in previous studies on print exposure effects (Cipielewski & Stanovich 1992; Cunningham & Stanovich 1990, 1991). The version used in this investigation consisted of a total of 35 items: 26 actual children's book titles and 9 foils for book names. In selecting the items to appear on the TRT, an attempt was made to choose titles that were not prominent parts of the classroom reading activities in the particular school participating in this investigation. Because we wanted the TRT to probe out-of-school rather than school-directed reading, an attempt was made to avoid authors and books that were regularly studied in the school curriculum. Of course, versions of the TRT constructed for other classrooms will quite necessarily differ somewhat in item content. The foils were generated by the authors and randomly interspersed among the actual book titles.

The instructions that were read to the subjects and that were printed on their response sheets were as follows: "Below you will see a list of book titles. Some of the titles are the names of actual books and some are not. You are to read the names and put a check mark next to the names of those that you know are books. Do not guess, but only check those that you know are actual books. Remember, some of the titles are not those of popular books but are made-up titles, so guessing can easily be detected." The TRT was group administered and took approximately 5 minutes to complete. The score on the task was the proportion of correct titles checked minus the proportion of foils checked, yielding a derived score which was used in all analyses. The split-half reliability of the correct titles (Spearman-Brown corrected) was 0.67.

Pseudoword reading. The children were asked to read 10 pseudowords taken from Coltheart and Leahy (1992): drack, lail, fump, drace, stell, hane, fide, hile, ving, and biss. They were told "I am going to show you some made-up words on these cards, I'd like you to read them out loud to me. Try your best to read them to me." This task took approximately 5 minutes to administer.

Metropolitan Reading Achievement Test (MAT). An achievement test of reading and spelling ability (MAT6, Elementary – Form L, 1984) was administered. The Elementary level of this measure contained the following subtests: vocabulary, word recognition, reading comprehension, and spelling. Of these, we focused only on students' performance on the word recognition subtest. Standard scores were used in all statistical analyses.

Table 3. First principal component loadings for all the orthographic variables

Variable	
Letter string choice 1	0.613
Letter string choice 2	0.824
Letter string choice 3	0.808
Orthographic choice	0.678
Homophone choice	0.829
PIAT spelling	0.872

% variance accounted for 60.3%.

Results

Descriptive statistics

Table 1 presents descriptive statistics on each of the variables. The means, standard deviations and skewness of the phonological, orthographic, and word recognition measures are displayed. Table 2 presents the correlations among all of the major variables in the study. All of the phonological tasks displayed significant, moderate correlations. The mean correlation across all pairs of phonological tasks was 0.53. Fifteen of the sixteen correlations among the orthographic processing tasks were statistically significant and most were of moderate size. The mean correlation across all pairs of orthographic tasks was 0.52. The phonological tasks all displayed significant correlations with the word recognition measure (Metropolitan subtest), ranging from 0.35 to 0.57. Likewise, all of the orthographic tasks displayed significant correlations with word recognition ability, ranging from 0.45 to 0.68. The phonological tasks all displayed significant correlations with the measure of print exposure (TRT) – the correlations ranging from 0.40 to 0.72. Likewise, all of the orthographic tasks displayed significant correlations with the measure of print exposure – the correlations ranging from 0.44 to 0.63.

The relationships among the orthographic tasks were explored using a principal components analysis. This analysis revealed only one component with an eigenvalue greater than one. The first principal component accounted for 60.3% of the variance and, as is clear from Table 3, all of the orthographic processing tasks had high loadings on this component.

Table 4.

Step	Variable	R	R^2 change	F change
Unique variance in word recognition predicted by orthographic processing after phonological processing variance is partialed out				
1.	Pseudoword reading (1st)	0.448	0.201	9.31**
2.	Phonological Composite	0.629	0.195	11.61**
3.	Orthographic Composite	0.747	0.163	12.91**
Unique variance in word recognition predicted by phonological processing after orthographic processing variance is partialed out				
1.	Orthographic composite	0.702	0.492	35.86***
2.	Phonological composite	0.743	0.059	4.75*
Unique variance in word recognition predicted by orthographic processing after phonological processing variance is partialed out				
1.	Pseudoword reading (3rd)	0.714	0.509	37.36***
2.	Nonword repetition	0.764	0.075	6.34**
3.	Orthographic composite	0.821	0.089	9.24**

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
Note: Phonological Composite = phoneme deletion-onset, phoneme deletion-initial blend, phoneme deletion-final blend, phoneme oddity, nonword repetition Orthographic Composite = letter string choice 1, letter string choice 2, letter string choice 3, orthographic choice, homophone choice, PIAT Spelling.

Orthographic and phonological processing as predictors of word reading

In order to simplify the regression analyses, two composite scores were constructed. The first, the phonological processing composite score, was composed of phoneme deletion-onset, phoneme deletion-intial blend, phoneme deletion-final blend, phoneme oddity, and nonword repetition. Pseudoword reading was treated as a separate variable because unlike the tasks in the phonological composite, it involves grapheme to phoneme coding. The five variables used for the phonological composite were standardized and summed. Likewise, the orthographic composite was constructed by summing the standardized scores from the six orthographic tasks: letter string choice 1, letter string choice 2, letter string choice 3, orthographic choice, homophone choice, and PIAT Spelling.[1]

A series of hierarchical regression analyses were conducted in order to explore the relationships between phonological processing, orthographic processing, and print exposure as predictors of word recognition ability. In the first analysis displayed in Table 4, first-grade pseudoword reading ability was entered first and accounted for 20.1% of the variance in MAT word recognition. The phonological composite variable accounted for 19.5% of the variance after pseudoword reading had been entered. Together, the pseudoword reading measure and the phonological composite (composed of five different tasks), accounted for 39.6% of the variance in word recognition ability and probably nearly exhaust the variance attributable to phonological processing (indeed, the pseudoword reading variable does not account for additional variance after the phonological composite has been entered). Finally, entered third into the regression equation is the orthographic composite and it accounts for a statistically significant and substantial portion of unique variance (16.3%). Thus, even after the variance in word recognition attributable to phonological processing has been removed, orthographic processing ability predicts additional variance. In the next analysis displayed in Table 4, we see that the converse is also true. That is, after the orthographic processing composite is entered (explaining 49.2% of the variance), the phonological composite predicts a statistically significant proportion of additional variance (5.9%; $p < 0.05$).

In the previous two analyses, the covariates (first-grade pseudoword reading and the phonological composite) were composed of tasks that had largely been administered prior to the orthographic processing tasks. It is thus possible that unique variance explained by the orthographic processing measures was in part due to their measurement being closer to that of the criterion measure (third-grade Metropolitan reading). The final analysis displayed in Table 4 was structured so as to preclude this possibility. The first covariate–pseudoword reading ability in the third-grade – was measured one year *after* the orthographic measures were assessed. The second covariate – nonword repetition ability – was measured at the same time as the orthographic tasks. As the final analysis in Table 4 indicates, these two covariates accounted for a substantial amount of variance in third-grade word recognition ability (58.4%). Nevertheless, the orthographic processing composite score still accounted for a significant amount of unique variance (8.9%).

The analyses presented in Table 5 examine the question of whether unique variance in word recognition is predicted by print exposure after the contribution of phonological processing has been partialed out. In the first hierarchical regression analysis displayed in Table 5, first-grade pseudoword reading ability was entered first and accounted for 33.4% of the variance in the orthographic processing composite variable. The phonological composite variable accounted for 9.9% of the variance after first-grade pseudoword reading had been entered. Together, the pseudoword reading measure and the phonological composite (composed of five different tasks), accounted for 43.3% of

Table 5.

Step	Variable	R	R^2 change	F change
Unique variance in orthographic processing composite predicted by print exposure after phonological processing variance is partialed out				
1.	Pseudoword reading (1st)	0.578	0.334	18.57***
2.	Phonological composite	0.658	0.099	6.25*
3.	Title recognition test	0.742	0.117	9.14**
1.	Pseudoword reading (3rd)	0.515	0.265	12.98**
2.	Nonword repetition	0.656	0.165	10.15**
3.	Title recognition test	0.802	0.213	20.23***

*p < 0.05, **p < 0.01, ***p < 0.001.
Note: Phonological Composite = phoneme deletion-onset, phoneme deletion-initial blend, phoneme deletion-final blend, phoneme oddity, nonword repetition Orthographic Composite = letter string choice 1, letter string choice 2, letter string choice 3, orthographic choice, homophone choice, PIAT Spelling.

the variance in orthographic processing ability. Finally, entered third into the regression equation is our measure of print exposure (the TRT) and it accounts for a statistically significant portion of unique variance (11.7%). Thus, even after the variance in orthographic processing attributable to phonological processing has been removed, print exposure predicts additional variance. In the next analysis displayed in Table 5, we see that this finding was duplicated when two other phonological processing covariates (third-grade pseudoword reading ability and nonword repetition) were employed. After these two covariates were entered, print exposure accounted for a statistically significant 21.3% of the variance. It should be noted that although the print exposure measure (the TRT) was assessed after the criterion measure in these analyses (that is, in third grade rather than second), the retrospective use of print exposure measures has been justified both empirically and theoretically in Cunningham and Stanovich (1997). Briefly, the idea is that although print exposure was not measured contemporaneously, TRT performance presumably reflects variance in exposure not just at the time of testing but also variance occurring during earlier years as well. Thus, we viewed the third-grade measure as in some sense a retrospective indicator tapping the cumulative experiences that had occurred several years previously and up to the time of testing. Empirically, the actual retrospective reach of the instrument is examined in Cunningham and Stanovich (1997).

Finally, additional analyses not reported in Tables 4 and 5 indicated that when the TRT, phonological composite, and orthographic composite were used as predictors of third-grade word recognition neither the TRT nor the phonological composite explained unique variance but the orthographic composite did (unique variance explained = 11.2%, $F(1,35) = 8.77$).

Discussion

There were consistent indications of a moderate degree of task convergence among the orthographic measures in our study. First, fifteen of the sixteen correlations among the orthographic processing tasks were statistically significant. Most of these correlations were moderate in size. The mean correlation across all pairs of orthographic tasks was 0.52. Similarly, each one of the orthographic tasks displayed a significant correlation with word recognition ability (in the range of 0.45 to 0.68) and with the measure of print exposure (in the range of 0.44 to 0.63).

The suggestion of moderate convergent validity was reinforced by the results of the principal components analysis. The first principal component was a very dominant component and accounted for 60.3% of the variance. All six measures of orthographic processing had loadings on the first principal component of more than 0.60. The second principal component had an eigenvalue of less than one.

The hierarchical regression analyses presented in Table 4 indicate that a composite measure of orthographic processing skill predicted significant proportion of the variance in word recognition after the variance accounted for by the phonological processing measures had been partialed out. This result held across a variety of phonological processing covariates that were employed. Thus, the linkage between orthographic processing ability and word recognition skill seems not to be the result of spurious linkages between orthographic processing skill and phonological abilities. Individual differences in orthographic processing skill do not seem to be totally parasitic on the operation of phonological processes.

One limitation of the present investigation was that several of the orthographic choice tasks had very modest reliabilities. This has also been the case in previous investigations using similar measures (Stanovich & Siegel 1994). Perhaps the reliabilities of these tasks could be enhanced with individual administration and with greater experimenter involvement to discourage guessing. Trial-by-trial, rather than list presentation might also help to raise reliability. Nevertheless, the orthographic composite remained a potent predictor even in the face of the modest reliabilities of the tasks that composed it. External processing requirements are of course implicated in all of the tasks – which is why investigations that search for convergent validation, like the present one, are necessary. For example, the phonological oddity task has memory requirements (although minimal in our three-item task) that create nonspecific associations. Nevertheless, despite this, convergent patterns both within this study and across similar studies are beginning to emerge in this research area.

The data provide at least a tentative indication that phonological and orthographic processing skills are separable components of variance in word recognition during the beginning stages of reading acquisition. Such a conjecture would be consistent with the suggestion that these two sources of variance contribute differentially to reading difficulties (Bryant & Impey 1986; Castles & Coltheart 1993; Freebody & Byrne 1988; Manis et al. 1996; Stanovich & Siegel 1994; Stanovich et al. 1997; Treiman 1984). Also consistent with this conjecture is the finding that print exposure explained variance in orthographic processing that was independent of phonological processing ability – a relationship that has been found in several previous studies (Barker et al. 1992; Braten et al. 1999; Cunningham & Stanovich 1990; Chateau & Jared 2000; McBride-Chang et al. 1993; Olson et al. 1994).

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Note

1. An alternative composite measure was analyzed which included the third grade spelling subtest of the Metropolitan Achievement Tests. Results using this alternative composite were virtually identical.

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