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Lexical processing skill in college-age resilient readers

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Abstract Despite an extensive literature linking individual differences in phonological processing to reading ability, some adults show normal text comprehension abilities despite poor pseudoword reading (Jackson & Doellinger (2002). *Journal of Educational Psychology, 94*, 64–78). This study was undertaken to investigate differences between these individuals, termed resilient readers, and proficient readers in performance and degree of lateralization on a variety of single word processing tasks. Participants completed seven divided visual field tasks investigating various aspects of reading. Resilient readers performed less accurately on basic word recognition tasks, but not on the tasks involving semantic access. Resilient readers did not differ from proficient readers on reaction time or lateralization on any of the experimental tasks. These findings are consistent with the hypothesis that skilled phonological decoding is not necessary for reading for meaning in a college population. It is proposed that higher-level semantic information and general world knowledge may allow some readers to compensate for deficiencies in lower-level word recognition processes.

Keywords Adult · Compensation · Language lateralization · Phonology · Reading comprehension

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Introduction

In traditional accounts, development of reading skill is proposed to rely crucially on phonological processing. There is an extensive literature linking individual differences in phonological awareness to reading ability (Badian, 2001; Manis, Custodio, & Szeszulski, 1993; Pratt & Brady, 1988; Scarborough, 1989; Wagner & Torgesen, 1987). In children, pseudoword reading is highly predictive of reading ability (Duncan & Johnston, 1999; Pratt & Brady, 1988; Rack, Snowling, & Olson, 1992). These correlations can be explained by assuming that an individual who has developed adequate phonological knowledge will possess representations of speech sounds which are capable of being matched to letters and blended together to pronounce new words; in contrast, an individual without adequate phonological knowledge will find letter-sound correspondences arbitrary and the acquisition of normal reading skills will be much more laborious (Wagner & Torgesen, 1987).

There is debate as to whether a similar relationship between phonological processing ability and reading achievement exists in the adult population. Some studies have shown that phonological processing measures are predictive of the text comprehension abilities of college students (Bell & Perfetti, 1994; Martino & Hoffman, 2002). However, a number of case studies of adults suggest that poor phonological decoding skills do not necessarily lead to poor word reading or reading comprehension skills (Holmes & Standish, 1996; Howard & Best, 1997; Stothard, Snowling, & Hulme, 1996). Jackson and Doellinger (2002) identified a group of six university students termed "resilient readers" because they obtained average or above average scores on tests of text comprehension despite poor decoding ability, as measured by standardized pseudoword reading tests.

It is possible that the terms "resilient reader" and "compensated dyslexic" describe the same population. Resilient readers display a behavioral profile similar to that of compensated dyslexics, adults who have achieved good reading skills despite childhood diagnoses of dyslexia. Compensated dyslexics continue to show deficits in phonological processing and pseudoword reading although their comprehension abilities are within the normal adult range (Bruck, 1990; Gallagher, Laxon, Armstrong, & Frith, 1996; Lefly & Pennington, 1991; Wilson & Lesaux, 2001). However, it is frequently difficult to determine whether resilient readers were reading disabled at some point in their lives. Of the six resilient readers studied by Jackson and Doellinger (2002), only one ever reported having been identified as having a reading disability or other learning problem. Two of the three subjects of case studies showing a pattern of poor decoding relative to text comprehension were not identified as having reading or spelling problems in the course of their schooling and the third received only extra spelling instruction for a short period of time (Holmes & Standish, 1996; Howard & Best, 1997; Stothard et al., 1996). Regardless of the childhood skills of resilient readers, what is apparent is that in their adult life, they are able to comprehend text well despite poor pseudoword reading.

The areas of skill and deficit shown by resilient readers could shed further light on the role of phonological processing in adults. College students vary widely in their skill at phonological analysis (Annett, 1999; Jackson, 2005; Martino & Hoffman, 2002) and it is important to determine what the consequences of this variation might be. Previous studies of how resilient readers differ from normal readers have yielded mixed results. Across studies, resilient readers have shown a deficit in spelling (Campbell & Butterworth, 1985; Holmes & Standish, 1996; Jackson & Doellinger, 2002). They were also out-performed by controls on a measure of rapid automatic naming (Jackson & Doellinger, 2002). Resilient readers have been shown to differ on measures of short-term memory and phonological awareness in some cases (Campbell & Butterworth, 1985; Holmes & Standish, 1996) but not others (Jackson & Doellinger, 2002). Resilient readers were slower to read passages (Jackson & Doellinger, 2002), but not single words (Campbell & Butterworth, 1985). They did not differ from controls on measures of verbal intelligence (Jackson & Doellinger, 2002), listening comprehension (Jackson & Doellinger, 2002), or lexical decision (Holmes & Standish, 1996). These results suggest that skilled phonological decoding is more likely to be necessary for skilled spelling and rapid naming than for higher-order measures like listening comprehension and verbal intelligence. The current study set out to test the hypothesis that poor pseudoword reading does not necessarily lead to poor performance on higher-order tasks by systematically varying the degree to which tasks require semantic access.

These previous studies of resilient readers have had several limitations. All have had small sample sizes, the majority being case studies (Campbell & Butterworth, 1985; Holmes & Standish, 1996; Howard & Best, 1997). The current study included twice as many resilient readers as the largest sample previously presented (Jackson & Doellinger, 2002), and may therefore have more power to detect differences between groups. Many of the previous studies have included few (Howard & Best, 1997) or no (Jackson & Doellinger, 2002; Stothard et al., 1996) measures of reaction time. As it is possible that normal accuracy is achieved at the cost of speed, the current study reports reaction times for the majority of tasks.

Differences in lateralization of language function in individuals with different levels of reading skill have long been a subject of investigation. Controversy remains over whether poor readers show altered lateralization in brain morphology (Hynd, Semrud-Clikeman, Lorys, Novey, Eliopulos 1990; Leonard, et al., 1993; Rumsey et al., 1997), brain activity as measured by functional neuroimaging (Brunswick, McCrory, Price, Frith, & Frith, 1999; Ingvar et al., 2002) and dichotic listening (Brunswick & Rippon, 1994; Obrzut, Oburzut, Bryden, & Bartels, 1985). One potential reason for discrepancies between studies is that the nature and degree of performance differences between reading groups has varied widely. An advantage to investigating lateralization in resilient readers is that they differ from controls primarily in one aspect of reading.

The current study set out to address the question of whether groups differing primarily in pseudoword reading show different patterns of lateralization on a wide variety of divided visual field (DVF) language tasks. In the DVF paradigm, stimuli are briefly presented to the left or right side of a fixation point in order to direct the initial processing of the stimulus to the right or left hemisphere, respectively. This paradigm has long been used to investigate hemisphere differences in language processing (for a review see Chiarello, 1988). For word recognition tasks like those used in this study, participants typically respond more quickly and accurately when items are presented to the right visual field/left hemisphere than the left visual field/

right hemisphere. If resilient readers show an altered degree of behavioral asymmetry, this would suggest that word recognition deficits are more pronounced in one cerebral hemisphere than the other. This could indicate that processing differences between resilient and typical readers have lateralized neural substrates. Some evidence in support of the idea that individuals with poor pseudoword reading show altered behavioral lateralization comes from a case study of a compensated dyslexic who showed a pattern of unusually large leftward asymmetries on DVF tasks involving word recognition (Chiarello, Lombardino, Kacinik, Otto, & Leonard, 2006a). This case study might suggest that individuals with poor pseudoword reading may also have word recognition deficits that are more pronounced in the right hemisphere. The present study investigated whether this pattern of asymmetries would generalize to a larger sample of resilient readers.

In the current study, 16 resilient readers with low scores on the Word Attack subtest of the Woodcock Reading Mastery Test—Revised/Normative Update (WRMT-R/NU, Woodcock, 1998) and average or above average scores on the WRMT-R/NU Passage Comprehension subtest and 16 proficient readers with average or above average scores on both subtests were selected from a large sample of college students. Participants completed seven DVF tasks (pseudoword naming, word naming, masked word recognition, lexical decision, category generation, verb generation, and semantic decision). These tasks were chosen to tap a variety of reading-related skills, ranging from phonological decoding to accessing word meaning relationships.

The lateralized pseudoword naming task was selected in order to determine whether the poor performance on the standardized pseudoword reading measure generalized to another experimental situation in which the pseudowords were shorter and contained fewer syllables than the Word Attack items. Three word recognition DVF tasks (pseudoword naming, word naming, masked word recognition) were included in order to determine whether resilient readers showed an altered level of performance or asymmetry on basic word recognition tasks. It was predicted that resilient readers would perform more poorly on these tasks because the tasks rely heavily on lower-level word identification processes.

A lexical decision task was also administered. This task can be influenced by a number of different processes including phonological decoding, recognition on the basis of the word's form, or semantic access (Balota & Chumbley, 1984). Because semantic information can be used to perform this task, it is predicted that resilient readers will not differ from proficient readers on this task. This is in keeping with a case study which found that a resilient reader did not show impaired performance on this task (Holmes & Standish, 1996).

Additionally, participants completed three DVF tasks that required semantic access (Category Generation, Verb Generation, and Semantic Decision). Stanovich (1980) proposed that deficiencies in lower-level processes like decoding can be compensated for by greater reliance on semantic factors like context. This hypothesis is supported by a number of studies showing that younger and poorer readers rely more on context while reading than older, more skilled readers (Briggs, Austin, & Underwood, 1984; Juel, 1980; Nation & Snowling, 1998). In a case study of a resilient reader, accuracy in reading pseudohomophones was improved by preceding the pseudohomophone with a related word (TOMATO-SAWCE) (Stothard et al., 1996), suggesting that the semantic information supported word identification. If resilient readers are relying on semantic information to compensate for poor phonological decoding skills, they will perform at least as well as proficient readers on those tasks necessitating semantic access.

Resilient readers are proposed to rely on some form of compensation (Holmes & Standish, 1996; Jackson & Doellinger, 2002; Stothard et al., 1996) to achieve normal word reading in the absence of skilled phonological processing. It is possible that while this compensation allows for normal accuracy, resilient readers are relying on a less efficient reading mechanism which cannot process written information as quickly. In this study, all tasks involved responding to stimuli presented briefly (for 30–150 ms), and could therefore present a challenge to a system that is compensating by reading through a less efficient mechanism. If resilient readers' normal accuracy on semantic tasks is achieved through reliance on a substantially less efficient reading system, their reaction times will be slower than those of the proficient readers.

It was predicted that the resilient readers in this study would show the pattern of unusually large leftward asymmetries for word recognition tasks shown by the compensated dyslexic student described by Chiarello et al. (2006a). More specifically, resilient readers were predicted to show abnormally low accuracy in the left visual field in the pseudoword and word naming and masked word recognition tasks that do not require semantic access. Resilient readers were not predicted to show altered asymmetry on the semantic tasks (Category and Verb Generation or Semantic Decision) as their performance was expected to mirror that of proficient readers.

Method

Participants

A total of 141 university students (71 female) tested in the Biological Substrates for Language Project (Chiarello et al., 2006b) participated in this study. All were native speakers of English with normal or corrected-to-normal vision and ranged in age between 18 and 34. In the full sample, decoding skills and comprehension ability were linked, with a correlation of 0.43 ($p < 0.001$).

Out of this sample, 25 students scored below the 25th percentile on the WRMT-R/NU Word Attack subtest. Of these 25 participants, 16 had scored above the 45th percentile on the WRMT-R/NU Passage Comprehension subtest (Woodcock, 1998) and were identified as resilient readers. These resilient readers showed a large discrepancy between their performance on the Word Attack and Passage Comprehension subtests, averaging a difference of 46.8 percentile points. In this group, the correlation between scores on the Word Attack and Passage Comprehension subtests was -0.17 ($p > 0.50$).

Sixteen proficient readers were selected to match these resilient readers as closely as possible on several background measures and on verbal and performance

Table 1 Mean raw scores, scaled scores and percentile ranks (range) on standardized tests of reading and intelligence for proficient and resilient readers

	Proficient readers	Resilient readers	*t*-value	*p*-value	Cohen's *d*
*Word attack**					
Raw score	40 (38–41)	30 (26–33)			
Scaled score	104 (98–111)	86 (81–90)			
Percentile rank	61(46–76)	18 (10–25)	16.28	<.0001	5.78
Passage comprehension					
Raw score	60 (55–68)	57 (53–63)			
Scaled score	111 (101–124)	106 (98–120)			
Percentile rank	74 (53–94)	64 (45–91)	1.80	>.05	0.64
*Word identification**					
Raw score	98 (90–101)	93 (85–99)			
Scaled score	102 (92–110)	96 (86–104)			
Percentile rank	56 (30–74)	39 (18–60)	3.45	<.005	1.21
Verbal IQ					
Scaled score	108 (95–139)	107 (95–127)			
Percentile rank	70 (37–99)	68 (37–96)	0.36	>.10	0.13
Performance IQ					
Scaled score	107 (91–119)	106 (93–119)			
Percentile rank	68 (27–86)	66 (32–86)	0.64	>.10	0.11
Age	20.3 (18–22)	20.3 (18–24)	0.14	>.10	0.05
Sex	9 Male, 7 female	9 Male, 7 female			
Handedness	5 Non-right handed	4 Non-right handed			

Statistical tests were done using percentile ranks based on age norms

intelligence. (see Table 1). Proficient readers scored above the 45th percentile on both the Word Attack and Passage Comprehension subtests of the WRMT-R/NU. The mean discrepancy in scaled score between the Word Attack and Passage Comprehension subtests for the proficient readers was 12.7 percentile points. The correlation between reading subtests in this group was 0.44 ($p = 0.09$), closely matching that of the full sample.

On the Word Attack subtest, resilient and proficient readers differed on both more and less difficult items. The subtest is ordered according to difficulty, with more difficult items appearing later. On each third of the items, resilient readers produced fewer correct responses than proficient readers: least difficult, 88.3% versus 100%, $t(28) = 3.66$, $p < .001$, $d = 1.38$; middle in difficulty, 75.4% versus 94.1%, $t(28) = 4.39$, $p < .0005$, $d = 1.66$; most difficult, 35.4% versus 70.8%, $t(28) = 3.36$, $p < .005$, $d = 1.27$. When the Word Attack items were classified according to length, resilient readers also produced fewer correct responses than proficient readers: 2–3 letters, 89.1% versus 99.5%, $t(22) = 3.13$, $p < .005$, $d = 1.33$; 4–5 letters, 63.1% versus 85.1%, $t(40) = 2.63$, $p < .05$, $d = 0.83$; 6 or more letters, 49.5% versus 82.8%, $t(22) = 3.01$, $p < .01$, $d = 1.28$.

Procedure

In a two-hour preliminary session, participants completed a 5-item hand preference questionnaire (Bryden, 1982), questionnaires regarding language and family background, and standardized measures of reading skill and intelligence. The Word Identification, Word Attack, and Passage Comprehension subtests of the WRMT-R/NU (Woodcock, 1998) were administered to assess participants' abilities to read real words, pseudowords, and to supply contextually appropriate completions to stimuli of increasing complexity. Age norms from the normative update were used to calculate scaled scores and percentile ranks. Verbal and performance intelligence were assessed using the Weschler Abbreviated Scale of Intelligence (Wechsler, 1999).

Following this session, four test sessions were held on separate days in which participants completed 7 lateralized word recognition tasks. After the final DVF task, participants completed the Adult Reading History Questionnaire (ARHQ) (Lefly & Pennington, 2000), designed to indicate a childhood history of reading disability.

Divided visual field tasks

Stimuli for all DVF experiments consisted of 3–6 letter concrete nouns or pronounceable pseudowords. All pseudowords were created by replacing a single letter of a concrete noun, with each position of replacement occurring equally often. No stimuli were repeated within an experimental session, and no stimulus was used more than twice throughout the whole study. Word lists for each task were equated for word length and log-transformed word frequency based on the Hyperspace Analogue to Language corpus (Lund & Burgess, 1996). Mean word length for each task ranged from 4.44 to 4.64 and mean log word frequency ranged from 4.16 to 4.71. Within each task, items were matched across visual field conditions on the basis of length, log frequency (Lund & Burgess, 1996), familiarity (Wilson, 1988) and imageability (Wilson, 1988).

All stimuli were presented in uppercase, black 20 point Helvetica font on a white background. Macintosh computers were used for stimulus presentation and recording of manual responses in the visual field tasks. Psyscope programming software (Cohen, Mac Whinney, Flatt, & Provost, 1993) was used to control experimental events and record responses. Participants were seated 60 cm in front of the monitor, using a headrest to stabilize head position. For those experiments requiring manual responses (Lexical Decision, Masked Word Recognition, and Semantic Decision), participants used their index fingers of each hand on the '.' and 'x' keys to indicate one response and the middle fingers of each hand on the '/' and 'z' keys to indicate the other response. This configuration was designed to accommodate both left- and right-handed participants. A Sony ECM-MS907 microphone was used to register vocal responses. Vocal responses were entered into the data file by an experimenter. Special codes were entered for spurious vocal responses (a cough, for example), or failure to respond, and such trials were not analyzed.

Each DVF task began with practice trials, followed by the experimental trials. For four tasks (Lexical Decision, Category Generation, Pseudoword Naming, and Semantic Decision), half of the items appeared in the left visual field and half of the items appeared in the right visual field. In the other three tasks, (Word Naming, Verb Generation, and Masked Word Recognition), a third of the items appeared in each visual field and the remaining third appeared in the center of the screen, immediately above the fixation point. This central condition was included in order to determine whether group differences existed only for lateralized stimuli. Subjects were instructed that the experiments investigated their ability to recognize words they were not directly looking at. They were told to maintain fixation on the central '+' fixation marker whenever it appeared on the screen, and to respond as quickly and accurately as possible. On each trial, the fixation marker appeared for 600–805 ms and flickered just prior to the onset of the stimulus. The stimulus word appeared randomly in the LVF, RVF or in the center of the screen. On LVF and RVF trials, the innermost edge of the stimulus was 1.8 degrees eccentric from the fixation marker. In order to prevent foveation of the stimuli, the duration of stimulus presentation was brief, ranging from 30–155 ms. Additional information regarding experimental design for each task is presented in Table 2. The 7 experimental tasks are described below:

Pseudoword Naming: Participants viewed pseudowords and pronounced them.

Lexical Decision: Participants viewed letter strings and indicated with a keypress whether each item was a word or a pseudoword. Half of the items were words and half were pronounceable pseudowords.

Word Naming: Participants viewed words and pronounced each.

Masked Word Recognition: Participants viewed a word presented for 30 ms immediately preceded and followed by a pattern mask (@#@#) presented for 60 ms. Two words, differing by one letter, then appeared in the center of the screen, one above the other, and participants indicated by keypress the one which had been shown in between the symbols.

Category Generation: Participants viewed category names (e.g. FRUIT) and named a member of that category (e.g. APPLE).

Verb Generation: Participants viewed nouns (e.g. SCISSORS) and said a verb associated with the noun (e.g. CUT). Participants were instructed to respond with "what the object does or what it can be used for".

Semantic Decision: Participants viewed nouns and indicated by keypress whether each word represented something naturally occurring or manmade.

Table 2 Duration of stimulus presentation and number of trials in each DVF task

	Central trials?	Duration of stimulus presentation (ms)	Number of practice trials	Number of experimental trials
Pseudoword naming	No	150	45	90
Lexical decision	No	125	48	180
Word naming	Yes	125	44	135
Masked word recognition	Yes	30	36	150
Category generation	No	155	32	82
Verb generation	Yes	150	32	150
Semantic decision	No	120	30	120

Results

The ARHQ was administered in order to investigate participants' current and childhood experiences with reading. The questionnaire is designed to provide a cut-score above which scores indicate childhood history of reading disability. Three resilient readers and no proficient readers had scores indicative of childhood reading disability.[1] As a group, however, the resilient readers did not score significantly higher on this measure than proficient readers ($p > 0.2$, Cohen's $d = 0.46$). Thirteen of the resilient readers' scores fell within the range of proficient readers' scores on this measure. These results highlight the difficulty of identifying resilient readers purely on the basis of self-report.

Mixed design $2 \times 2 \times 7$ analyses of variance (ANOVAs) were performed on mean correct response times (RTs) and mean percent correct with the following variables: visual field (left or right), group (resilient or proficient), and task (Lexical Decision, Word Naming, Category Generation, Pseudoword Naming, Masked Word Recognition, Verb Generation, and Semantic Decision).[2] Group was the only between-subjects factor. For the tasks in which some items were presented centrally (Word Naming, Masked Word Recognition, and Verb Generation), performance on central trials was examined separately in order to determine whether group differences existed only for lateralized stimuli. Correct trials on which the RT was 2.5 or more standard deviations from the subject's mean were trimmed to subject's mean $\pm$ 2.5 SD. Means are given in Tables 3 and 4.

Visual field results

There was a significant effect of visual field on both RT $F(1, 30) = 68.79$, $p < .0001$ ($\omega^2 = 0.13$) and accuracy $F(1, 30) = 60.87$, $p < .0001$ ($\omega^2 = 0.12$). Participants responded more accurately to items presented to the RVF (87.2%) than LVF (78.9%), indicating better performance when items were directed to the left hemisphere. Participants were faster to respond to items presented to the RVF (1226 ms) than LVF (1308 ms). The visual field interactions with task and group were not significant ($p > 0.50$, $\omega^2 < 0.01$). To further test whether visual field effects were stronger in one group of readers than another, asymmetry indices were calculated for performance on each task ((LVF − RVF)/(LVF + RVF)). The groups do not statistically differ on this asymmetry index for any of the seven experimental tasks in either percent correct or RT, $t(30)$ from 0.237 to 1.890, Cohen's d from 0.09 to 0.66.

[1] While a score over 0.40 was considered indicative of a childhood history of reading disability by the designers of the ARHQ (Lefly & Pennington, 2000) a more stringent cut-off of 0.45 was used in this study. Two of the questions relate to the frequency with which participants read newspapers. Because very few of the college student participants in our study routinely read newspapers, their scores appeared artificially inflated. Therefore, we adopted a cut-off score of 0.45 to avoid falsely classifying participants as having a history of reading disability.

[2] Separate 2×2 ANOVAs were also performed for each task with visual field (left or right) and group (resilient or proficient) as variables. The results of these separate analyses mirror those reported here, with no significant 2-way interactions of group and visual field, and significant effects of group in accuracy for Word Naming, Pseudoword Naming, and Masked Word Recognition.

Table 3 Mean percent correct (standard deviation) for each DVF task

	Proficient readers	Resilient readers
Left visual field		
Pseudoword naming	77.4 (21.5)	58.9 (19.0)
Word naming	84.0 (11.0)	76.6 (11.4)
Masked word recognition	76.0 (9.6)	66.5 (9.6)
Lexical decision	68.1 (16.0)	64.0 (13.1)
Category generation	91.9 (9.7)	86.7 (10.6)
Verb generation	93.2 (6.4)	93.0 (6.0)
Semantic decision	86.1 (9.8)	81.7 (10.9)
Right visual field		
Pseudoword naming	78.9 (16.4)	64.2 (25.0)
Word naming	94.8 (3.5)	89.7 (5.1)
Masked word recognition	82.8 (10.6)	76.4 (7.3)
Lexical decision	88.1 (7.5)	86.9 (8.8)
Category generation	94.4 (5.4)	91.5 (6.0)
Verb generation	96.3 (4.1)	93.3 (5.5)
Semantic decision	93.0 (4.5)	90.1 (4.9)
Central visual field		
Word naming	99.4 (1.4)	96.0 (4.9)
Masked word recognition	92.3 (10.3)	88.0 (8.0)
Verb generation	97.6 (2.4)	96.3 (3.4)

Because the groups did not differ in lateralization, the average RT and percent correct across the left and right visual fields will be used in further analyses (see Fig. 1). Mixed design 2 × 7 ANOVAs were performed on mean correct RTs and mean percent correct with group (resilient or proficient) and task as variables. For reaction time, there was a main effect of task $F(6, 30) = 171.2$, $p < 0.0001$ ($\omega^2 = 0.82$), reflecting the differences in difficulty between DVF experiments. Participants were fastest to respond in Word Naming (809 ms) and Lexical Decision (841 ms), followed by Pseudoword Naming (988 ms), Semantic Decision (1118 ms), and Masked Word Recognition (1165 ms). Participants took longest to respond on the semantic generation tasks, Verb Generation (1754 ms) and Category Generation (2180 ms). The main effect of group and the group by task interaction were not significant (ps > 0.50, $\omega^2 < .01$). Across all experiments, the mean RT for proficient readers was 1,260 ms and the mean RT for resilient readers was 1,274 ms. For the tasks with central trials (Word Naming, Masked Word Recognition, and Verb Generation), there were no significant differences between groups in RT, $t(30)$ from 0.479 to 0.715, d from 0.17 to 0.26.

For accuracy, there was a main effect of task $F(6,30) = 42.41$, $p < 0.0001$ ($\omega^2 = 0.53$), reflecting the differences in difficulty between DVF experiments. Participants were most accurate on the Category Generation (94.0) and Verb Generation tasks (91.1), followed by Semantic Decision (87.7) Word Naming (86.3), Lexical Decision (76.8), and Masked Word Recognition (75.4). Participants

Table 4 Mean reaction time (standard deviation) for each DVF task

	Proficient readers	Resilient readers
Left visual field		
Pseudoword naming	917 (214)	1043 (241)
Word naming	825 (173)	861 (192)
Masked word recognition	1283 (363)	1198 (297)
Lexical decision	920 (215)	858 (166)
Category generation	2239 (553)	2229 (446)
Verb generation	1755 (321)	1810 (242)
Semantic decision	1163 (235)	1176 (252)
Right visual field		
Pseudoword naming	914 (192)	1078 (329)
Word naming	769 (171)	779 (140)
Masked word recognition	1064 (284)	1115 (250)
Lexical decision	809 (140)	776 (129)
Category generation	2177 (469)	2075 (402)
Verb generation	1695 (330)	1754 (244)
Semantic decision	1054 (204)	1077 (227)
Central visual field		
Word naming	654 (158)	693 (163)
Masked word recognition	937 (205)	964 (222)
Verb generation	1647 (336)	1696 (230)

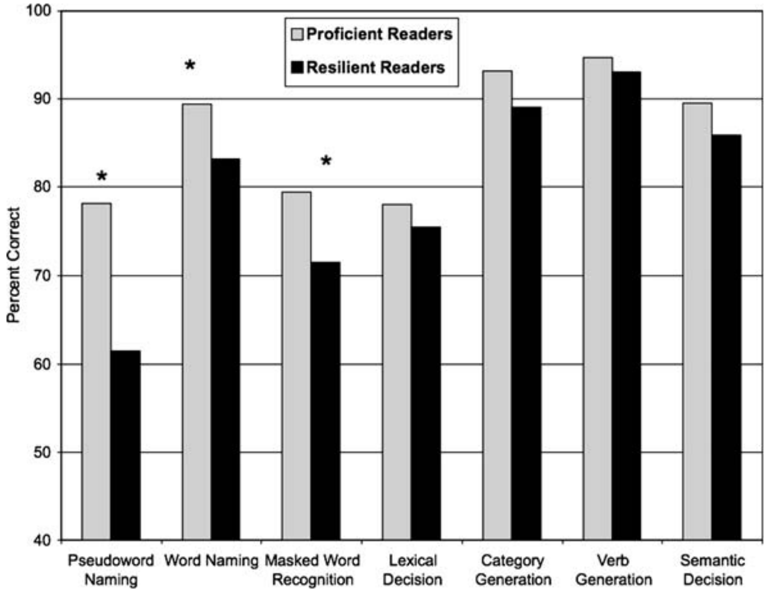

Fig. 1 Mean accuracy for each reading group on each DVF task

were least accurate at Pseudoword Naming (69.9). There was also a main effect of reading group $F(1, 30) = 8.01$, $p < 0.01$ ($\omega^2 = 0.16$), with resilient readers being less accurate (80.0) than proficient readers (86.1). These main effects were moderated by a significant group by task interaction, $F(6, 180) = 3.39$, $p < .01$ ($\omega^2 = 0.06$). Pairwise comparisons show that proficient and resilient readers differ in accuracy on only three of the seven DVF tasks (see Fig. 1). Resilient readers were significantly less accurate (61.5) than proficient readers (78.5) at Pseudoword Naming $t(30) = 2.65$, $p < 0.05$ $d = 0.97$, Word Naming (83.2 versus 89.4) $t(30) = 2.65, p < 0.05$ $d = 0.97$, and Masked Word Recognition (71.5 versus 79.4) $t(30) = 2.72$, $p < 0.05$, $d = 0.99$. Of the tasks with central trials, resilient readers were less accurate in Word Naming (96.0 versus 99.4) $t(30) = 2.66$, $p < 0.05$ $d = 0.97$, and did not differ in Masked Word Recognition ($t = 1.33$) or Verb Generation ($t = 1.27$).

Extreme groups

While the phonological decoding scores of the resilient readers in this study were well below average, they were not so extreme as to fit typical clinical definitions of poor performance. In order to examine whether the pattern of results that characterized the full sample of resilient readers was typical of the poorest phonological decoders, six individuals with scaled Word Attack scores below 85 were matched with six controls on the basis of several background measures and on verbal and performance intelligence. The results with this smaller, more extreme sample closely match those of the full sample.

In order to examine differences in laterality in these more extreme groups, mixed design $2 \times 2 \times 7$ analyses of variance (ANOVAs) were performed on mean correct response times (RTs) and mean percent correct with the variables visual field, group, and task. The two-way interaction between group and VF was not significant for accuracy ($F < 0.50$, $\omega^2 < 0.03$) or RT ($F < 3.00$, $\omega^2 < 0.15$). The three-way interaction between group, VF, and task was also not significant for either accuracy ($F < 0.50$, $\omega^2 < 0.13$) or RT ($F < 2.1$, $\omega^2 < 0.34$). The smaller groups do not statistically differ on the asymmetry index for any of the seven experimental tasks in either percent correct or RT, $t(10)$ from 0.12 to 2.1, Cohen's d from 0.07 to 1.33.

Mixed design 2×7 ANOVAs were performed on mean correct RTs and mean percent correct with more extreme group (resilient or proficient) and task as variables. For RT, the main effect of group ($F < 0.30$, $\omega^2 < 0.02$) and the group by task interaction ($F < 1.70$, $\omega^2 < 0.30$) were not significant. For the tasks with central trials (Word Naming, Masked Word Recognition, and Verb Generation), there were no significant differences between groups in RT, $t(10) < 0.40$, $d < 0.25$. Pairwise comparisons confirmed that the more extreme groups of proficient and resilient readers did not differ in RT on the DVF tasks. The smaller groups of resilient and proficient readers did not significantly differ in RT averaged across LVF and RVF, t from 0.06 to 1.56, d from 0.04 to 0.99 or from centrally presented stimuli, t from 0.19 to 0.37, d from 0.12 to 0.23. For accuracy, there was a significant main effect of reading group $F(1, 10) = 7.56$, $p < 0.005$ ($\omega^2 = 0.58$), with resilient readers being less accurate (75.4) than proficient readers (85.5). This main effect was moderated by a significant group by task interaction, $F(6, 60) = 7.56$, $p < .0001$ ($\omega^2 = 0.77$). Pairwise comparisons show that the more extreme groups of proficient and resilient readers differ in accuracy on the three DVF tasks on which the larger groups differed in accuracy. When performance was averaged across LVF and RVF presentation, resilient readers were significantly less accurate (50.8) than proficient readers (84.9) at Pseudoword Naming $t(10) = 4.18$, $p < 0.005$, $d = 2.64$, Word Naming (78.1 versus 89.0) $t(10) = 3.66$, $p < 0.005$, $d = 2.31$, and Masked Word Recognition (67.1 versus 77.9) $t(10) = 2.65$, $p < 0.05$, $d = 1.68$. When performance on centrally presented trials was examined, resilient readers were less accurate at Word Naming (92.7 versus 99.6) $t(10) = 2.45$, $p < .05$, $d = 1.55$ and Masked Word Recognition (85.3 versus 94.0) $t(10) = 2.25$, $p < .05$, $d = 1.42$. The smaller samples also differed in accuracy of Verb Generation, $t(10) = 3.07$, $p < .05$, $d = 1.94$ when accuracy was averaged across LVF and RVF but not when central performance was examined $t = 1.26$, $d = 0.80$. Like the larger samples, the smaller groups did not differ in accuracy on the Lexical Decision, Category Generation, or Semantic Decision tasks (t from 0.47 to 0.88, d from 0.30 to 0.56).

On first glance, it may appear that the groups differ primarily on the tasks with lowest accuracy. However, poor performance in resilient readers on some tasks will by definition result in low overall accuracy for those tasks. To avoid this circularity, the average accuracy of proficient readers was used as an index of task difficulty. This index resulted in the following order of task difficulty: Verb Generation (94.7%), Category Generation (93.1%), Semantic Decision (89.6%), Word Naming (89.4%), Masked Word Recognition (79.4%), Pseudoword Naming (78.2%), Lexical Decision (78.1%). The tasks on which resilient readers perform equivalently to proficient readers span the range of task difficulty as measured by accuracy among proficient readers. The groups perform similarly on the task with lowest accuracy among proficient readers (Lexical Decision) and the three tasks with highest accuracy (Semantic Decision and Verb and Category Generation) and differ on the three tasks with an intermediate level of difficulty (Word Naming, Masked Word Recognition, and Pseudoword Naming). In two cases, tasks with very similar accuracy differ in the demand they place on semantic processing. The Pseudoword Naming and Word Naming tasks (which do not require semantic access) show similar accuracy to the Lexical Decision and Semantic Decision tasks. In both of these cases, the groups differ only on the task, which does not require semantic access.

It is possible that resilient readers sacrifice accuracy in order to achieve normal reaction times, answering impulsively before a correct response can be generated. To address this possibility, correlations were performed between resilient readers' accuracy and RT for each task. If resilient readers' poor accuracy is related to impulsivity, it would be predicted that those individuals with lowest accuracy would be those with the fastest reaction times and correlations between accuracy and reaction time would be positive. In contrast to this hypothesis, correlations between accuracy and reaction time for each task were negative (Semantic Decision $r = -0.021$, Category Generation $r = -0.141$, Word Naming, $r = -0.194$; Verb Generation $r = -0.217$, Masked Word Recognition $r = -0.222$, Lexical Decision

$r = -0.414$, Nonword Naming, $r = -0.454$), indicating that those individuals who were fastest to respond were also more likely to be accurate.

Differences between resilient and proficient readers might stem either from the specific combination of poor phonological decoding abilities and normal text comprehension or from a large discrepancy between the two abilities. In order to investigate whether the pattern of performance shown by resilient readers would be shown by participants with a large discrepancy between phonological decoding and passage comprehension abilities at another level of reading skill, additional analyses were performed. From the full sample of 141 university students, 16 individuals with Word Attack performance above the 45th percentile and the largest discrepancy between Word Attack and Passage Comprehension scores were selected. Each of these individuals was matched to a low-discrepancy participant using the same process that matched proficient and resilient readers. These high ability groups that differed in discrepancy did not differ in average accuracy for any of the experimental tasks ($p > 0.30$, Cohen's $d < 0.3$). These results suggest that differences between resilient and proficient readers stem from abnormally low phonological decoding abilities combined with normal text comprehension, not simply from a large discrepancy between the two abilities.

Discussion

In this study, resilient readers were found to be significantly less accurate than proficient readers on measures of basic word recognition, but not less accurate on tasks which involve semantic access. Resilient readers did not appear to achieve high levels of performance on semantic tasks through reliance on a less efficient compensatory mechanism, as they did not differ in reaction time on any of the experimental tasks. Resilient and proficient readers did not differ in lateralization on any of the experimental tasks.

This study has several limitations. While the sample size is at least twice as large as previous studies of resilient readers (Holmes & Standish, 1996; Howard & Best, 1997; Jackson & Doellinger, 2002; Stothard et al., 1996), it is still small, so subtle differences between resilient and proficient readers might have been missed. The implications of this study for reading development are limited by the lack of data on the childhood reading of participants. Future studies should also be aimed at investigating the orthographic analysis skills of resilient readers to determine whether they contribute to the skilled performance.

The overall pattern of results suggests that resilient readers differ from their typical reading peers primarily on accuracy of response for Pseudoword Naming, Word Naming, and Masked Word Recognition, the tasks that do not require semantic access, but not the tasks that do require semantic access (Semantic Decision, Verb Generation, and Category Generation). These findings are in keeping with previous studies which have shown that resilient readers perform equivalently to controls on measures such as verbal intelligence and listening comprehension (Jackson & Doellinger, 2002), and show deficits in tasks like spelling and phonological awareness (Campbell & Butterworth, 1985; Holmes & Standish, 1996; Jackson & Doellinger, 2002).

Resilient readers did not perform less accurately on Lexical Decision. This finding agrees with a case study reporting that a resilient reader performed particularly well on this task (Holmes & Standish, 1996). A lexical decision can be influenced by a number of different processes including phonological decoding, recognition on the basis of the word's form, or semantic access. Several findings suggest that semantic processing may be involved in the lexical decision task. Semantic variables such as meaningfulness (Balota & Chumbley, 1984), category dominance (Balota & Chumbley, 1984), and number of word meanings (Borowsky & Masson, 1996; Pugh, Rexer, & Katz, 1994) have been demonstrated to affect lexical decision performance. Additionally, models in which semantic units contribute to lexical decisions have replicated a variety of effects produced by humans (Borowsky & Besner, 1993; Plaut & Booth, 2000). It is possible that resilient readers do not differ from proficient readers on this task because they perform it by relying on the semantic processes that are their strength.

Why resilient readers fail to apply semantic processing for Word Naming and Masked Word Recognition tasks remains an open question. One possibility is that the nature of the semantic tasks constrains the stimulus set to a greater degree in the semantic tasks, and resilient readers are able to make use of this information. For example, participants are aware that a stimulus in the Category Generation task will be a category name, but are unaware of such constraints in the basic word recognition tasks. Such information may lead to more accurate word identification in the semantic tasks even when the initial processing of the stimulus is incomplete.

In this adult sample in which groups differ primarily in pseudoword reading ability, poor phonological processing impacted word recognition performance but not performance on tasks involving semantic access. These results suggest that skilled phonological decoding is not necessary for reading for meaning in these college students. These findings are consistent with the hypothesis that higher level contextual processes can compensate for deficiencies in lower level processes like phonological decoding (Stanovich, 1980). Previous studies have suggested that resilient readers are able to perform normally on tasks that involve accessing word meanings (Holmes & Standish, 1996; Howard & Best, 1997; Jackson & Doellinger, 2002; Stothard et al., 1996) and experience an increased benefit from semantic context (Stothard et al., 1996). In children at risk for dyslexia, high IQ and good oral language skills have been proposed as protective factors (Snowling, Gallagher, & Frith, 2003). Similarly, in adults with a childhood diagnosis of dyslexia, listening comprehension and vocabulary moderate the relationship between phonological skill and reading comprehension (Ransby & Swanson, 2003). It is suggested, then, that skill in deriving meanings from words and strong general knowledge are the mechanism by which resilient readers achieve normal comprehension in the absence of skilled phonological decoding.

The pattern of skill and deficit shown by resilient readers appears to result from the combination of abnormally poor phonological decoding and normal text comprehension. A group of more skilled readers with a similar discrepancy between their Word Attack and Passage Comprehension scores did not differ from a control group on any of the experimental tasks. The poor phonological processing skills of resilient readers may mean that this group must develop strong semantic skills in order to achieve normal reading for meaning.

The resilient readers in this study did not differ from controls in degree or direction of asymmetry on any of the visual field tasks presented to them. This is in contrast with a previous study showing extremely large visual field differences for word recognition tasks in a student whose performance on psychometric tests and DVF tasks paralleled that of resilient readers (Chiarello et al., 2006a). Previous results regarding alteration of behavioral asymmetries in poor readers have been inconsistent (Brunswick & Rippon, 1994; Obrzut et al., 1985). It is possible that variations in asymmetry are related to subject characteristics other than phonological decoding skill. In addition to the poor word decoding, the subject of the Chiarello case study had difficulty with spelling, grammar, verbal working memory, and math fluency, none of which were assessed in the current study. It is also possible that poor phonological processing may arise from a number of different mechanisms, some of which are associated with alteration of lateralization and others which are not.

The lack of a significant interaction between group and visual field suggests that processing differences between resilient and poor readers are not restricted to one hemisphere. The reduced accuracy on word recognition tasks shown by resilient readers was equivalent in the two visual fields, suggesting that differences in word recognition skill between groups were not restricted to the left hemisphere. Resilient readers' performance on semantic tasks was equivalent to controls in both visual fields, suggesting that semantic access is normal regardless of which hemisphere initiates processing.

If resilient readers rely on a less efficient compensatory process, it would be expected to result in longer reaction times. However, resilient readers responded as quickly as control readers on all seven DVF tasks, even the word decoding tasks on which they were less accurate. This finding is consistent with a case study that reported that a resilient reader showed normal reaction times on pseudoword reading and phoneme awareness tasks on which her accuracy was low (Holmes & Standish, 1996). Among dyslexics, the speed of reading has been shown to be related to the amount of reading done for pleasure (Leiononen et al, 2001). It is possible that the reading speed of the resilient readers in this study has allowed them to gain experience from reading equivalent to that of controls. In turn, this reading experience might contribute to general world knowledge, and may help explain the academic achievement of the resilient readers. Resilient readers also did not show increased reaction times for the tasks requiring semantic access. This suggests that the process by which resilient readers achieve normal performance on such tasks is no less efficient than that used by proficient readers.

This study suggests that in at least some adults, phonological decoding ability plays less of a role than it has been shown to play developmentally (Duncan & Johnston, 1999; Pratt & Brady, 1988). Because the only available source of information about these resilient readers' childhood reading is their own recollection of their education history, it is difficult to determine whether these students showed a similar discrepancy between phonological decoding and reading comprehension as children. It is possible that resilient readers' comprehension skill masked an underlying deficit in phonological processing so that they were never identified as reading disabled. It is also possible that resilient readers once possessed age-appropriate phonological decoding skills which deteriorated or failed to develop with time. Future longitudinal studies are necessary to determine how phonological decoding and passage comprehension are related at different stages in the development of reading skill.

This study identified a population of college students who experience difficulty in reading pseudowords and doing tasks that require word identification in isolation but perform normally on tasks that require controlled semantic processing. It is possible that such readers are able to attain their high level of reading comprehension and academic achievement by relying on top-down information to compensate for difficulties in applying bottom-up word identification processes. It appears that these top-down processes are quite efficient in both the cerebral hemispheres.

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