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Speaking up for Vocabulary: Reading Skill Differences in Young Adults

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Abstract

This study is part of a broader project that has the goal of developing cognitive and neuro-cognitive profiles of adolescent and young adult readers whose educational and occupational prospects are constrained by their limited literacy skills. The study explores relationships among reading related abilities in participants aged 16 to 24 years spanning a wide range of reading ability. Two specific questions are addressed: (1) Does the Simple View of Reading (Gough & Tunmer, 1986) capture all non-random variation in reading comprehension? (2) Does orally-assessed vocabulary knowledge account for variance in reading comprehension, as predicted by the Lexical Quality Hypothesis (Perfetti & Hart, 2002)? A comprehensive battery of cognitive and educational tests was employed to assess phonological awareness, decoding, verbal working memory, listening comprehension, reading comprehension, word knowledge, experience with print. In this heterogeneous sample, decoding ability clearly plays an important role in reading comprehension. Gough and Tunmer's Simple View of Reading gives a reasonable fit to the data, though it does not capture all of the reliable variance in reading comprehension as predicted. Orally assessed vocabulary knowledge captures unique variance in reading comprehension even after listening comprehension and decoding skill are accounted for. We explore how a specific connectionist model of lexical representation and lexical access can account for these findings.

Surprisingly, the cognitive bases of reading differences in young adults have not been nearly as well-studied as have those of learners in the primary school years (Curtis, May, 2002). This is especially true for individuals who are not college-bound. Our study was motivated by a desire for a better understanding of the reading-related abilities of young people who, for whatever reason, have failed to attain a level of reading proficiency adequate to the demands of the modern workplace. Consequently, we have recruited young people, aged 16-24 years, representing a wide spectrum of abilities and educational backgrounds. While our approach was to sample broadly, we focused on settings (adult schools, community colleges) that experience suggests will include a significant number whose reading skills are poorly developed, such that their future educational and occupational prospects are limited (Shankweiler, Lundquist, Dreyer, & Dickinson, 1996; Dietrich & Brady, 2001). Reading abilities of the participants range from 5th grade to post-high school. Their educational

environments at the time of participation range from high-school and adult-school through community college. Reading research and language comprehension research alike have neglected unskilled readers who may not meet legally established criteria for learning disability. An adequate understanding of the reading-related limitations of the many young people outside the 'university' track of the traditional post-secondary educational system is badly needed in order to plan effective adult education and remedial programs.

We take two proposals about reading skill as our point of departure. The Simple View of Reading proposes that reading comprehension is literally the product of decoding skill and general language comprehension capacity (Gough & Tunmer, 1986), when each are measured appropriately. A tenet of the Simple View is that decoding, the ability to identify words by way of orthographic to phonologic mapping, is the one new skill that an individual must acquire in order to learn to read. A second proposal, the Lexical Quality Hypothesis, focuses on the role of word knowledge in the reading process, positing that skilled reading depends on high quality lexical representations (Perfetti & Hart, 2002). Specifically, this thesis holds that robust word knowledge, including knowledge of syntactico-semantic relationships among words, facilitates printed word recognition when decoding cues are weak. In evaluating these proposals, we adopt an analytic approach based on regression modeling to take advantage of the fact that people vary continuously in their reading skill and in the underlying capacities that support it. Our theoretical perspective is grounded in connectionist views of word knowledge (e.g. Seidenberg & McClelland, 1989).

The Simple View of Reading

Reading is among the most highly complex skills that school children are called upon to master, and it is influenced by a variety of perceptual, linguistic, and cognitive abilities. Gough and Tunmer (1986) found it useful to cope with this complexity by framing the Simple View of Reading. The Simple View separates the variables pertaining to reading success into two groups. One group consists of those skills related to printed word recognition as such. It comprises the visual and visual-to-phonologic (and morphologic) mapping skills that are needed to productively derive word meanings from print representations. Call this group of abilities D, for decoding. The other group of abilities includes the many factors that reading shares with spoken language: vocabulary, syntax, semantics and pragmatics, to name some of the chief ones. Call them L, for language. Each group of variables is, obviously, complex. Gough and Tunmer proposed that R, or reading comprehension, is the product of D and L and that, when these are properly measured, they account for all of the variance in R.

The choice of indices for each group of D and L is an important consideration for any investigation of reading ability. D is typically assessed by skill in reading nonwords and L is ordinarily identified with comprehension of spoken sentences or narrative passages. Hoover and Gough (1990, p. 130) define decoding, D, as "the ability to rapidly derive a representation from the printed input that allows access to the appropriate entry in the mental lexicon, and thus, the retrieval of semantic information at the word level." This definition of decoding is general enough to cover several plausible specific mechanisms: (i) decoding could be a purely visual pattern recognition skill, in which visual patterns are directly associated with semantic and syntactic information in the lexicon; (ii) decoding could activate the lexical entries indirectly, via a phonological channel. Hypothesis (ii) itself can take a range of forms: (ii.a) the mapping from orthographic words to phonological words could be accomplished purely by rote, (ii.b) it could be a systematic map, a rule-based system, which takes advantage of the regularities in the relationships between letters and sounds, or (ii.c) it could be some combination of (ii.a) and (ii.b). Hoover and Gough clearly favor possibility (ii.b). In their study, they measure readers' ability to correctly pronounce orthographically legitimate nonwords and use that score as an index of decoding skill. Our test battery includes the Word Attack task

from the Woodcock-Johnson -- III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001), a nonword reading task that closely corresponds to hypothesis (ii.b). In our initial implementation of the Simple View, this nonword-reading measure is used as the index of decoding ability.

For beginning readers, it is clear that lack of decoding ability is the primary obstacle to fluent reading (Adams, 1990; Snow, Burns, & Griffin, 1998). The primary locus of reading difficulty seems to be different for older students and adults. For them, it is thought that the demands of text reading more often reflect challenging content and vocabulary, which heavily involve the L side of reading. Indeed, it has been claimed that among adult readers differences in listening comprehension (L) alone account for most of the variance in reading comprehension (Palmer, MacLeod, Hunt, & Davidson, 1985). However, there is considerable evidence to suggest that, even among more mature readers, decoding skill continues to account for unique variance in reading comprehension (Bell & Perfetti, 1994; Cunningham, Stanovich, & Wilson, 1990; Lundquist, 2004; Shankweiler et al., 1996).

In order to fairly assess the relationship of listening comprehension to reading comprehension, it is necessary to have measures of each that are well-calibrated to one another. In the present study, we accomplished this by splitting materials from the Peabody Individual Achievement Test -- Revised (PIAT-R; Markwardt, 1998) reading comprehension sub-test into parallel sets to assess print comprehension and speech comprehension. We also assess participants' ability to comprehend short narrative passages in print. However, where the comparability of reading comprehension and listening comprehension tasks is critical, we make use of the PIAT-R based comprehension measures.

A corollary of the Simple View is that potential reading comprehension capacity will be limited by the capacity to comprehend equivalent material in spoken form. Given this proviso, reading disability is best characterized as a discrepancy between achieved reading skill and comprehension of speech, rather than as a discrepancy between reading comprehension and general cognitive capacity (Aaron, 1997; Gough & Hillinger, 1980; Perfetti, 1985; Stanovich, 1991).

Although the Simple View explains a lot about reading skill, there have been suggestions that it can be improved upon. For example, reading fluency is known to be well correlated with overall reading skill (Fuchs, Fuchs, Hosp, & Jenkins, 2001). Further, nearly all who meet accepted criteria for reading disability are deficient in word reading speed and/or accuracy (Fletcher et al., 1994; Stanovich & Siegel, 1994). Joshi and Aaron (2000) propose that "the rate at which the written word is processed should be considered as a factor to be reckoned with in reading" independent of general comprehension and decoding skill. Their proposal calls for supplementing the model of reading based on the two-factor Simple View with an additional component of processing speed. In another connection, Shankweiler et al. (1996) suggest that, as readers mature, fine-grained knowledge of relationships among words, including derivational morphology and orthographic conventions, gained through experience with both spoken and written language, is an increasingly important component of reading skill. In the following section, we turn to the Lexical Quality Hypothesis put forward by Perfetti and Hart (2002), a proposal which, we believe, has the potential to account for inter-relationships among word knowledge, lexical processing speed, and reading skill.

The Role of Word Knowledge

A link between word knowledge and reading comprehension is plausible on its face and empirical support is well-established (for example: Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Cunningham et al., 1990; McKeown, Beck, Omanson, & Pople, 1985). Perfetti and Hart (2002; Perfetti & Lesgold, 1979) maintain that the quality of lexical representations

influences the ease with which those representations can be accessed. In this context, quality refers to the extent that a lexical representation includes all staple components of a word (orthographic, phonologic, and syntactico-semantic), the richness of the specification of each component, and the degree to which the components are integrated with each other.

We propose that the Lexical Quality Hypothesis implies a differential effect of modality, such that comprehension of print depends on high quality lexical representations to a greater extent than does comprehension of speech. We will expand on this idea in the Discussion. Here, we anticipate that discussion with a set of observations. First, we note that, in general, linguistic comprehension depends both on information from the sensory input systems and listener/reader knowledge of linguistic structure and contextual constraints. As the linguistic signal becomes less informative (noisier/weaker), top-down constraints become more important to the process of comprehension (Elliott, 1979; Kalikow, Stevens, & Elliott, 1977). Moreover, print is, in many ways, an impoverished linguistic signal relative to speech. Not only is print, for many, a less-practiced modality, it also lacks information found in speech, as from coarticulation and prosody. Further, print often has less contextual support than speech. Thus, individual variation in the availability of top-down constraints (specifically, word knowledge), or in the ability to exploit them, may explain some differences in comprehension, particularly where the linguistic signal is weak. The Lexical Quality Hypothesis focuses on top-down influences on lexical access stemming from the organization of lexical knowledge internal to the reader. We are specifically interested in the effect of lexical quality on lexical access when bottom-up cues (visual/acoustic) to word identity are relatively weak. We leave aside the, albeit important, issue of readers' capacity to exploit contextual constraints in support of word identification as discussed in Stanovich (1980) and much subsequent work.

In order to assess word knowledge, our battery includes measures of both expressive and receptive vocabulary. We chose orally administered tasks to avoid confounds with reading comprehension. Given the importance of vocabulary to comprehension, a deeper understanding of its precursors is desirable. Two measures included in our battery have, in other studies, predicted significant variance in word knowledge: experience with print and verbal working memory. We examine the relative contributions of these two factors to word knowledge in our study population.

Stanovich, West and Harrison (1995; also see Stanovich & Cunningham, 1992; West & Stanovich, 1991; West, Stanovich, & Mitchell, 1993), in a study of college students and older adults, found that print experience was a reliable predictor of vocabulary even after differences in working memory, IQ and education were taken into account. Indeed, Perfetti and Hart also acknowledge the importance of reading experience to developing high quality lexical representations. Two closely related measures of print experience are included in our battery: magazine and author recognition checklists (Cunningham & Stanovich, 1990; Stanovich & Cunningham, 1992). In these tasks, participants have to distinguish actual magazine titles (author names) from foils consisting of fictional titles (or names). The checklists are scored using a signal detection logic in which participants are penalized for false-positive responses. Participants' age and years of education were also collected as indicators of more general experience.

A number of studies have observed a relationship between verbal working memory and children's word knowledge (Avons, Wragg, Cupples, & Lovegrove, 1998; Gathercole & Baddeley, 1990; Baddeley, Gathercole, & Papagno, 1998; but see Aguiar & Brady, 1991) and also of adults' ability to acquire new words in a second language (Atkins & Baddeley, 1998). We incorporate an auditory version of the Daneman and Carpenter (1980) sentence span task as an index of verbal working memory. This type of task is designed to tap both processing and short-term storage, thereby mirroring the challenge of reading texts or apprehending

spoken discourse. We use an auditory presentation of sentence materials, in a departure from most work using sentence span measures in adults, to avoid confounding differences in verbal working memory, as such, with differences in reading ability. On one common view, verbal memory includes an inherently phonological component (Baddeley, 1986; Shankweiler & Crain, 1986) which is a possible locus for the phonological constraints on both print and speech comprehension. There is evidence, however, that the variance in reading comprehension captured by measures of verbal working memory may be mediated by other factors; as noted, working memory has been shown to account for variance in word knowledge. To assess how closely the working memory exploited in reading is specific to language, our test battery also included a nonverbal test of memory for visual patterns, which can be viewed as a nonverbal analog of sentence span.

Questions to be Addressed

Our concern with the nature of reader differences and reading-related skills of young adults leads us to ask the following questions: (a) Does the two-factor Simple View of Reading give a satisfactory account of reading comprehension differences in this population as it does for learners in the elementary grades? (b) What are the relative contributions to reading comprehension of decoding and listening comprehension? (c) What factors, if any, pick up variance in reading comprehension after decoding and listening comprehension have been accounted for? (d) What is the relative contribution of word knowledge to comprehension of print and comprehension of speech?

Preview of Findings

The central finding we report below is that Gough and Tunmer's Simple View accounts for most of the variance in reading comprehension among the adolescent and young adults we studied. Moreover, decoding ability uniquely accounts for a significant proportion of the variance even among these 16-24 year olds. But we also find an additional, somewhat unexpected, result. Significant unique variance is captured by vocabulary knowledge, assessed via oral vocabulary tests. This outcome is surprising from the perspective of the Simple View, which holds that the effects of oral vocabulary knowledge should be entirely subsumed by General Language Comprehension. Perfetti and Hart's Lexical Quality hypothesis provides insight into this result: high-quality lexical representations compensate for the relative weakness of the print signal, as contrasted with the speech signal. To make this concrete, we describe, in the discussion section an activation-based model that predicts such modality differences.

Method

Participants

Our participants were young people, aged 16 to 24 years. In keeping with our interest in those who struggled in primary and secondary school, we specifically targeted adult education centers serving urban neighborhoods. There, we found individuals whose secondary schooling had been interrupted for one reason or another, but who were now seeking either a high school equivalency certificate or resuming a regular high school program at the center. Additionally, we recruited through advertisements in a local newspaper and posters placed on adult school and community college campuses, which brought in individuals with a wider range of backgrounds, but with abilities continuous with other participants. Nearly all participants were enrolled in some kind of educational program, whether high-school, adult-school or community college. A few were recent graduates and not enrolled in school at the time they participated in our study.

Those selected for participation had to be capable of reading simple material with understanding in order to perform our reading tasks. To determine this, we used the ‘fast-reading’ subtest of the Stanford Diagnostic Reading Test (SDRT; Karlson & Gardner, 1995). This 3-minute test consists of a short expository passage containing 30 choice points at which the participant is required to select the appropriate word from among three alternatives. In previous work with this population, we had determined that the proportion of correct responses was a better indicator of ability to perform our tasks than the absolute score. Thus, we set no minimum score, but required an accuracy of at least 70% correct of items attempted. This cutoff would exclude some severely reading disabled individuals, while admitting others who are accurate but slow. We also screened to ensure that participants had acquired English as their first language. Finally, participants were required to have an estimated full-scale IQ of 80 or above. All participants gave informed consent.

Data was collected from a total of 47 participants. Two, who failed to meet the minimum IQ requirement, were excluded from subsequent analyses. Data from one participant was identified as problematic and so excluded from all subsequent analyses; see the results section for details. Thus, analyses presented here are based on an N of 44 (18 male).

Participants were paid for completing the protocols described below, as well as eye-tracking and fMRI protocols which are reported elsewhere (in preparation). Altogether, testing time averaged about five hours over two sessions. All protocols were approved by the Yale University human investigation committee.

Measures for Assessment of Reading-related Skills

The measures are organized into the following groups: Group a) Print Mapping and Reading Skills: Reading isolated words, reading nonwords, pseudohomophone detection, reading comprehension, oral reading speed; Group b) Oral Language Measures: Phonological awareness, vocabulary, auditory verbal working memory, listening comprehension; Group c) Non-Linguistic Mental Facility and Speed: memory for visual sequences, analogical reasoning. In addition to the foregoing measures, we assessed experience with print via author and title checklists. In summarizing these measures below, we report the published reliabilities for published tests when these were administered in the standard way. Otherwise, we report reliabilities derived from our own data. We also report age and years of education completed at time of testing.

Group a: Print Mapping and Reading Skills

Nonword Reading: The Woodcock-Johnson III Word Attack sub-test, form A, served as a measure of rule-based decoding skill (Woodcock et al., 2001). Participants read-aloud individual pseudo-words presented in list form. This test is a relatively pure measure of skill in orthographic to phonologic decoding. Average reliability of this task across the age range of our study participants is .82 (McGrew & Woodcock, 2001).

Word-Reading: The Woodcock-Johnson III Word Identification sub-test, form A, provided a measure of memory-based decoding capacity (Woodcock et al., 2001). Participants read-aloud a list of individual words graded in difficulty. Because no contextual support is available, this test primarily taps decoding skill, but it is decoding of known word forms, rather than novel ones. Average reliability of this task across the age range of our study participants is .90 (McGrew & Woodcock, 2001).

Pseudohomophone Identification: For each item, participants must choose the one pseudo-word that would be pronounced like a real word, from among three alternatives (Olson, Forsberg, Wise, & Rack, 1994). Sixty triads of pseudo-word stimuli are presented by computer

using Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Accuracies and response times were recorded. This test taps decoding ability because it necessitates generating a phonological representation for each item, but it also requires the participant to compare the generated phonological form with representations stored in the mental lexicon; thus vocabulary knowledge is exercised as well. Reliability is $\alpha = .84$.

Print Sentence Comprehension: Our first of two reading comprehension measures is an abridged version of the reading comprehension sub-test from the Peabody Individual Achievement Test -- Revised (PIAT-R; Markwardt, 1998). Participants read a list of increasingly difficult sentences and then choose a picture, from an array of four, which best matches the meaning of the sentence. Odd numbered items from the subtest were administered in the standard way to assess reading comprehension, while even numbered items were used to assess listening comprehension as described below (Spring & French, 1990). The standard stop condition of 5 errors in 7 consecutive items was used for the abridged form. For the abridged form, we find a reliability of $\alpha = .90$; Leach et al. (2003) report a reliability of $\alpha = .89$ for a similarly abridged form of the task, administered to 4th and 5th grade students.

Print Passage Comprehension: Participants read aloud and answered questions about passages 5, 7 and 9 from the Gray Oral Reading Test, 4th edition, form A (GORT; Wiederholt & Bryant, 2001). Each of the passages was followed by five comprehension questions. The passage comprehension score is the total number of correct responses for the three passages. Reliability for the GORT subset used here is $\alpha = .67$.

Reading Speed: We collected and summed oral reading times for the three GORT passages. Reading speed was then calculated as the combined word count of the three passages (361; #5 = 106, #7 = 107, #9 = 148) divided by total reading time.

Spelling: Items consisted of 36 of the 72 words from the experimental spelling test of Shankweiler et al. (1996). Items were such that they could not generally be spelled simply by reference to letter-phoneme correspondence rules, but neither were their spellings highly idiosyncratic; the ability to spell items correctly depended on familiarity with a range of orthographic conventions as well as some common exceptions. Reliability is $\alpha = .87$.

Group b: Oral Language Measures

Phonological Awareness: A Spoonerism Production test was used to measure phonological awareness. This required participants to exchange the initial consonant for pairs of spoken names (Perin, 1983). For example, John Lennon is transformed into Lon Jennon. To carry out this task participants must hold the pair of stimulus names in memory, separate the initial phoneme from each, attach each severed phoneme to the alternate remainder and pronounce the newly synthesized items. Reliability is $\alpha = .94$. Response times were recorded in addition to accuracies (Paulesu et al., 1996).

Receptive Vocabulary: The Peabody Picture Vocabulary Test -- Revised (PPVT; Dunn & Dunn, 1997) requires the participant to select a picture from a group of four alternatives that best depicts a spoken target word. The average reliability across the age range of our population is .95 (ibid.).

Expressive Vocabulary: The vocabulary sub-test from the Weschler Abbreviated Scales of Intelligence (WASI; The Psychological Corporation, 1999) tests individuals' abilities to verbalize what they know of a word's meaning; the average reliability coefficient for adults (age ≥ 17) is reported as .94 (ibid.).

Verbal Working Memory: We used an auditory version of the sentence span task (Daneman & Carpenter, 1980), to assess working memory. Participants were required to judge increasingly long series of sentences (containing 2 to 5 items) as true or false and then, at the end of each series, to verbally recall the final words of every sentence in the series; words did not have to be recalled in the order presented. Scores correspond to the total number of items correctly recalled. Reliability is $\alpha = .85$. This type of task taps both processing and short-term storage, thereby mirroring a challenge presented by following discourse or reading texts. We administered the test in the auditory mode rather than the print mode to avoid confounding differences in verbal working memory, as such, with reading ability differences. Daneman and Carpenter referred to this variant as listening span.

Speech Sentence Comprehension: We used even numbered items from the PIAT-R reading comprehension sub-test (Markwardt, 1998) to assess listening comprehension, while odd numbered items were used to assess reading comprehension (Spring & French, 1990; Leach et al., 2003). This maneuver allows us to assess reading and listening comprehension with well-matched tasks. Parallel to the print form, participants attend to increasingly difficult tape-recorded sentences and, for each one, choose a picture from an array of four which best matches the meaning of that sentence. The standard stop condition of 5 errors in 7 consecutive items was used. For the subset of items used for listening comprehension, we find a reliability of $\alpha = .87$. Leach et al. (2003) report a reliability of $\alpha = .87$ for listening comprehension assessed in this way (with 4th and 5th grade students).

Group c: Non-Linguistic Mental Facility and Speed

Visual Memory: We used a computerized version of the Corsi blocks task (Corkin, 1974) implemented in Pyscope (Cohen et al., 1993). The participant has to reproduce increasingly long visuo-spatial patterns by tapping successively on an irregular arrangement of nine circles displayed on a touch sensitive computer screen. The patterns occur in blocks of five at each of the lengths three through ten. The participant's score is the longest sequence that she can successfully reproduce three out of five times. This is a purely nonverbal memory test; there is no obvious way to code the patterns verbally.

Matrix Reasoning: This is a test of visual-analogical reasoning from the WASI (The Psychological Corporation, 1999); the average reliability coefficient for adults (age ≥ 17) is .94 (ibid).

Other Measures

Print Experience: We used magazine and author checklists based on the work of Cunningham and Stanovich (1990; Stanovich & Cunningham, 1992) to assess experience with printed materials. In the magazine checklist, the participant has to distinguish actual magazine titles from foils consisting of fictional titles ($\alpha = .74$). True positive and false negative responses were used to compute accuracy scores penalized for guessing such that the reported scores are equal to the number of real titles checked minus the number of false-titles checked. The author checklist is similarly structured and scored ($\alpha = .86$).

Composite Measures—Our test battery contains content-overlapping measures for reading comprehension, vocabulary, and print experience. For data reduction purposes and to increase reliability, the following composite scores were generated: a) Reading Comprehension Composite is derived from PIAT-R print sentence comprehension, and GORT passage comprehension; b) Vocabulary Composite is derived from PPVT and WASI vocabulary; c) Print Experience Composite is derived from author and title recognition checklists.

Results

Data Preparation

Prior to analysis, distributions of variables were examined for deviations from normality and for outliers through inspection of quantile-quantile plots and histograms. Several variables show evidence of non-normality. For each such case, we used the method of maximum likelihood to estimate an unconditional Box-Cox power transformation to minimize deviations from normality (Atkinson, 1985). Primary analyses target composite measures of reading-comprehension and vocabulary; these composites show good distributional properties. We apply the Box-Cox power transformation to variables suffering from potentially problematic distributional properties wherever these occur as criterion measures. No obvious outliers were observed in the univariate distributions.

We checked for multivariate outliers in the most critical portions of the variable space by examining quantile-quantile plots of Mahalanobis distances against a χ^2 distribution with df equal to the dimensionality of the variable space. We examined two subsets of our variable space in this way. The first is defined by 5 variables: composite measures of reading comprehension and vocabulary, as well as speech sentence comprehension and the decoding measures of word and non-word reading. In the second case we examined a 7 dimensional space defined by the component measures of each of the two aforementioned composites, as well as the speech comprehension measure and the two decoding measures. In neither case did we observe any outliers.

We took the additional step of screening for data points likely to exert excessive influence on the fit of models of interest. As our primary focus is on reading comprehension, we fit all simple regressions targeting our composite measure of reading comprehension (rcomp-composite), as well as all simple regressions targeting the PIAT derived measure of print sentence comprehension (print-sentence-comp). We then checked for the presence of influential observations on the fit of each model by examining the Cook's distance statistic for each data point (Cook, 1977). Data from one participant was discovered to be problematic. That data point was observed to inflate correlations with reading comprehension, whether composite or simple, and each other variable under consideration. Thus, this participant is excluded from the summaries and analyses reported below. Recursive application of this procedure revealed no other problematic observations.¹

Descriptive Summary of Results of the Cognitive and Educational Tests

Means and standard deviations for each measure are shown in Table 1. Summaries of cognitive measures are based on raw scores. Where available, we also include grade-equivalent or age-equivalent scores.² Additionally, estimated full-scale IQ, based on the Vocabulary and Matrix Reasoning subtests from the WASI is included (The Psychological Corporation, 1999). For the poorer readers in our study, as defined by a median split on the reading comprehension screening measure, it is worth noting that scores on the PIAT-R based reading comprehension task (print-sentence-comp) are appreciably lower than scores for the corresponding listening comprehension task (speech-sentence-comp), which is based on the same set of materials (Wilcoxon signed rank test for paired samples: $n = 22$, $T^+ = 197$, $p < .05$). This indicates that the sample includes many whose ability to comprehend material in printed form is weak in

¹All statistical procedures were carried out with the R statistical system version 2.1 (R Development Core Team, 2004).

²The print-sentence-comp and speech-sentence-comp measures reported here are both derived from the PIAT-R reading comprehension sub-test. However, due to the non-standard method of administering these tasks, grade equivalent scores for these measures were calculated in the following way. The raw score, s , for each task was scaled according to the following formula ($s2+18$). This value was then entered into the reading comprehension column of table G1 in Markwardt (1998). Caution should be used in interpreting these derived scores.

relation to their capacity for comprehension of the same kinds of material in speech. The better readers showed no such discrepancy.

Table 2, below the diagonal, contains intercorrelations among measures from Table 1, as well as composites derived from those scores; above the diagonal are intercorrelations among age-partialled scores. In-text discussion refers to correlations among non-age-adjusted variables, unless otherwise noted.

We identify some of the correlations that will be salient in the regression analyses to follow, designating correlations of .6 or greater as strong and correlations greater than .3 but less than .6 as modest. Our chief criterion measure, the reading comprehension composite (rcomp-composite), correlates strongly with word-reading ($r = .76$) and modestly with pseudoword measures pseudohomophone identification accuracy (pseudohom-acc; $r = .46$) and nonword-reading ($r = .49$). In addition, there are strong correlations between reading comprehension and spoken language measures speech-sentence-comp ($r = .74$), vocabulary composite (vocab-composite; $r = .84$), and verbal working memory (verbal-memory; $r = .62$). Reading comprehension composite also correlates strongly with estimated print experience (printexp-composite; $r = .75$). Finally, it correlates with measures of nonlinguistic mental capacity wasi-matrices ($r = .60$) and visual-memory ($r = .42$).

Predicting Variation in Reading Comprehension

Testing the Simple View—Gough and Tunmer's (1986) Simple View of reading states that reading comprehension is the sole product of listening comprehension and decoding skill. The most direct implementation possible of the Simple View, given the tasks in our battery, predicts the reading comprehension composite from listening comprehension (speech-sentence-comp) and nonword-reading (WJ-III word-attack subtest, form A).³ We use simultaneous regression to assess how well the simple view fits our data. Age is included as a covariate in each model.

Table 2 (below the diagonal) shows that listening comprehension (speech-sentence-comp) alone captures 55% of the variance in our reading comprehension composite measure. Even if age is first partialled from each measure, there remains 44% shared variance (Table 2, above the diagonal). Table 3A shows the result of predicting the composite reading comprehension score from listening comprehension and nonword-reading, with age included as a covariate. This model captures 76% of the variance in reading comprehension. Thus, the Simple View provides a good account of the variation in reading comprehension in our data. As can be seen in the unique variance captured by each factor, listening comprehension and decoding ability make largely orthogonal contributions to reading comprehension (note the complete lack of correlation between the two predictors, Table 2). The addition of word-reading or pseudohomophone ID measures to 3A fails to improve prediction significantly, while nonword-reading remains a significant predictor in either case.

The Simple View ascribes all reading-specific variation to decoding skill alone. We wanted to know if any factors in addition to decoding play a significant role in predicting reading comprehension ability after listening comprehension ability is accounted for. To find out, we conducted an exhaustive search of linear models targeting the reading comprehension composite under the constraint that listening comprehension had to be included. We looked for models that captured as much variance as our implementation of the Simple View of

³Gough and Tunmer (1986) and Hoover and Gough (1990) actually propose a multiplicative model ($R = DL$), but Dreyer and Katz (1992) argue that the multiplicative model lacks a clear advantage over the corresponding additive model ($R = D + L$). A possible exception to this generalization arises in cases that approach the lower bound of nil reading achievement (Joshi & Aaron, 2000) but the reading levels of our participants, while deficient, are far from this region. In keeping with Dreyer and Katz, we focus on the additive version. We are motivated here by a desire to consider contributions of additional factors besides D and L, and it is straightforward to incorporate these into an additive model.

Reading. Only one model improves reliably on that of Table 3A. As predicted by the Lexical Quality Hypothesis (Perfetti & Hart, 2002), vocabulary knowledge accounts for a substantial portion of unique variance in reading comprehension.

The Role of Vocabulary Knowledge—As Table 2 indicates, our vocabulary composite (a combination of WASI Vocabulary and PPVT, both of which are administered orally) captures a large amount of the variance in our reading comprehension composite (71%). This is hardly a surprising result; not knowing the meanings of the words in a text is a major impediment to understanding it. Under the Simple View, the contribution of word knowledge to reading comprehension should be entirely subsumed under our measure of general language comprehension capacity (speech-sentence-comp).

However, when the vocabulary composite is added to the Simple-View-based model of Table 3A (76% of variance captured), it adds another 6% for a total of 82%; see Table 3B. Table 3 shows that the contribution of word knowledge to reading comprehension overlaps considerably with those of decoding and listening comprehension, but, contrary to the predictions of the Simple View, it is not wholly contained within them. Of exploratory models targeting reading comprehension with three or fewer factors, none capture as much variance as 3B. Moreover, no skill-based model with more than three factors improves significantly on 3B. As to experience-based measures, neither print-experience nor years of education adds to the predictive power of 3B ($F(1, 38) = 1.44$, ns and $F(1, 38) = 2.12$, ns, respectively).

Of course, it is to be expected that the vocabulary composite is well-correlated with reading comprehension, but the Simple View would not lead us to expect that it would capture significant unique variance beyond the contributions of listening comprehension and nonword-reading. Note that the vocabulary composite is based on two purely oral tests of word knowledge, so its contribution to reading comprehension is unlikely to stem from the existence of words known to some participants only in written form, or from a mismatch in the general linguistic knowledge needed to succeed on our reading comprehension and listening comprehension measures. However, in order to explore the latter possibility, we targeted our PIAT-R derived measure of reading comprehension, print-sentence-comp, which is well-matched to our listening comprehension measure, speech-sentence-comp (see Methods), with a model parallel to that in Table 3B. A Box-Cox power transformation has been applied to the criterion, print-sentence-comp, to ameliorate skewness. This model captures an essentially identical portion of variance to 3B, 82%. Listening comprehension, nonword-reading and vocabulary composite measures are all reliable contributors, capturing 4%, 3% and 7% of unique variance respectively.

The Lexical Quality Hypothesis, in conjunction with our conception of lexical representation and lexical access, leads us to investigate the relative contribution of vocabulary knowledge to comprehension of print and of speech. Based on those concerns, we predict that vocabulary knowledge will be more strongly predictive of reading comprehension than of speech comprehension. We test this prediction by examining the relative contribution of vocabulary to the prediction of each comprehension measure while taking the other into account. In each model, a Box-Cox power transformation is applied to both PIAT-R derived comprehension measures.

Unsurprisingly, given 3B, vocabulary predicts a large portion of unique variance in the print-sentence-comp measure of reading comprehension, as shown in Table 4A. The complementary model in 4B shows that vocabulary is not similarly predictive of speech comprehension. Of course, vocabulary and listening comprehension (speech-sentence-comp) are highly correlated (Table 2), the point of 4B is that vocabulary makes no unique contribution to the prediction of listening comprehension, after taking into account the contribution of reading comprehension

(and of age). The addition of nonword-reading to either of the models in Table 4 improves prediction slightly in both cases: $F(1,39) = 5.97, p < .05$ and $F(1,39) = 7.72, p < .01$, respectively. Moreover, vocabulary remains a significant predictor in the model targeting reading comprehension, while accounting for a non-significant portion of variance in the model targeting listening comprehension.

The asymmetry in the predictive power of vocabulary with respect to comprehension in each modality is also relevant to another matter. It is possible that the strong unique contribution of vocabulary to prediction of reading comprehension shown in 3B is due to our vocabulary measure picking up on residual unexplained variance due to the reduced precision of the PIAT-derived comprehension measures.⁴ Recall that our print-sentence-comp and speech-sentence-comp are each based on one-half of the materials in the 82 item PIAT sentence comprehension task (see Methods). Since the sentence comprehension subtest of the PIAT (Markwardt, 1998), from which our comprehension measures are derived, includes a carefully titrated range of vocabulary, from very familiar to very obscure, it is not unreasonable to suppose that the vocabulary tests tap word knowledge on which the two PIAT-derived measures differ. Based on our own data, the reliabilities of the two PIAT-derived measures are .90 and .87, respectively. On the other hand, the published reliabilities of the PPVT and WASI vocabulary measures are reported as .95 (Dunn & Dunn, 1997) and .94 (The Psychological Corporation, 1999). If the structure of measurement error were the explanation for the predictive power of vocabulary with respect to reading comprehension seen in Table 3, then we would expect approximate symmetry in the predictive power of vocabulary with respect to comprehension in each modality. As Table 4 shows, that prediction is clearly not supported.

Predicting Word Knowledge

Finally, we examine potential precursors to word knowledge. Two factors have some currency in the literature, print experience (e.g. Stanovich et al., 1995) and verbal working memory (e.g. Baddeley et al., 1998). Table 5A shows that the joint contribution of these two factors to vocabulary is substantial, accounting for 70% of the variance. Table 5B shows that verbal-memory and print experience remain reliable predictors of vocabulary even when other measures of memory and experience (visual memory and years of education completed) are included in the model as well. Moreover, the additional measures in 5B fail to improve prediction beyond 5A ($F(1,38) < 1$).

Discussion

We begin our discussion by surveying other research looking at reader skill differences among adults. Second, we consider the prediction of reading comprehension from the standpoint of The Simple View of Reading, with particular attention to the role of decoding. Then, we consider the interpretation of the observed increment in variance in reading comprehension that is attributable to verbally assessed measures of word knowledge, predicted by the Lexical Quality Hypothesis. Following this discussion of our findings, we outline our conception of word knowledge and show how it can explain observed differences between comprehension of speech and print. Finally, we discuss how other results from the literature on comprehension fit this conception of lexical quality.

The studies most nearly comparable to ours, in terms of the measures administered and age of the participants, were carried out by Cunningham, Stanovich and Wilson (1990), Lundquist (2004), and Ransby and Swanson (2003). The first two of these studies were based on college

⁴We are grateful to an anonymous JLD reviewer for pointing out this alternative hypothesis and suggesting a method (described below) of assessing it.

students, hence representing a narrower range of variation than that sampled in the present study. However, all of these studies attest to the continuing relevance of decoding differences among adult readers, finding a significant, though small, contribution of decoding to reading comprehension and reading efficiency measures.

As to the role of vocabulary, Cunningham et al. report that, in a model targeting reading comprehension with measures of listening comprehension, decoding skill and vocabulary, the latter accounted for a unique 6.5% of variance (of a total multiple R^2 of .58). Lundquist's findings also suggest that word knowledge plays a role in reading comprehension differences. He reports that a model predicting (Nelson-Denny) reading comprehension from (Nelson-Denny) vocabulary, verbal working memory (exactly the same listening span task that we used) and latencies to pronounce nonwords, accounts for 28% of variance in his sample of college students. However, the Lundquist study did not attempt to isolate the role of vocabulary from other measures of verbal ability, and so cannot speak directly to the question of whether vocabulary played an independent role over and above listening comprehension and decoding skill.

Ransby and Swanson (2003) focus on adult readers with childhood diagnoses of dyslexia, contrasting those individuals with age-matched and reading-level matched controls. They report that reader group alone predicted 36% of variance in reading comprehension, but the contribution of the group contrast became non-significant when either decoding skill or (orally-assessed) word-knowledge were used as auto-regressors. This would seem to indicate that both are possible contributors to variation in reading comprehension in their sample. Notably, a general test of language comprehension failed to fully obviate the contrast between reading disabled and age-matched controls.

Finally, Baddeley, Logie, Nimmo-Smith, and Brereton (1985), in a study based on a sample of adults with much wider ranges of age and ability, report that vocabulary is a reliable predictor of reading comprehension in a model that also includes a verbal sentence span measure similar to ours as well as a measure of non-verbal memory (counting span). They did not, however, take into account the contributions of listening comprehension or decoding skill to reading comprehension.

Decoding and the Simple View

Our test battery included three measures of decoding skill. The nonword-reading task is a relatively pure measure of rule-based decoding skill. The pseudohomophone ID task and the word-reading task each have requirements that overlap significantly with nonword-reading, but each also imposes unique task demands. Word-reading allows the practiced reader to leverage memory-based mappings between print and meaning. Pseudohomophone ID, on the other hand, requires the reader to use rule-based decoding skills to arrive at a phonological representation and then map that representation to a known word. So, the decoding requirements of pseudohomophone ID and nonword-reading are essentially the same, but word-reading taps a different aspect of decoding skill.

As we noted in Results, the addition of either word-reading or pseudohomophone ID measures to the model based on the Simple View (Table 3A) fails to improve the overall fit. However, several other studies have found that familiarity with specific orthographic--lexical (or sub-lexical) mappings is an important component of decoding skill. In one such study, Waters, Seidenberg and Bruck (1984) showed that beginning readers (primary school students) demonstrate a more robust orthographic regularity effect than do more experienced readers (college students). In other words, beginning readers are more effected than experienced readers by inconsistencies in orthography to phonology mappings. Presumably, younger

readers rely more heavily on rule-based decoding principles and, consequently suffer more when those principles fail them.

Further, Greenberg, Ehri and Perin (1997; also Read & Ruyter, 1985) found that even adults whose reading skills were quite poor were better than reading-level-matched children at reading atypically spelled words, a task which exercises memory-based decoding skill. Together, these findings suggest that adults rely more on memory-based mapping and less on analytic decoding routines than do younger readers. It is not clear whether the underpinnings of this trend lie in cognitive development or, perhaps, in differences in educational practices targeting younger versus older readers. Greenberg et al. also showed that adult poor readers were deficient in nonword reading relative to reading-level-matched children. This is significant because rule-based decoding skill is particularly important for the acquisition of new vocabulary via print. Our data indicate that a nonword-reading index of decoding skill accounts for variation in the reading comprehension of young adults, while word-reading does not. Both the present findings and the Greenberg et al. results indicate that variation in rule-based decoding skill is an important antecedent of reading skill even among adults. Thus, less-skilled adult readers are relatively deficient in precisely that aspect of decoding skill that should be most useful to them in supporting the acquisition of new words from print. Moreover, these facts help to substantiate Gough and Tunmer's (1986) choice of nonword-reading as the preferred index of decoding skill.

The Role of Vocabulary

The Lexical Quality Hypothesis states that comprehension depends on high quality lexical representations (Perfetti & Hart, 2002). This leads to the prediction that vocabulary knowledge should play an important role in accounting for differences in reading comprehension. Our data indicate that vocabulary does make a contribution to reading comprehension over and above the variance captured by listening comprehension and decoding skill, as Table 3B shows. This is consistent with the findings of Cunningham et al. (1990) and Ransby and Swanson (2003) discussed above. Importantly, the present work followed these previous studies in including well-matched listening comprehension and reading comprehension tasks.

Further, our conception of the Lexical Quality Hypothesis, which we expand upon in the next section, prompts us to surmise that top-down influences on comprehension (quality of lexical representations) are most important when bottom-up cues to meaning (provided by speech or print signal) are at their weakest. Hence, we predict an asymmetry in the contribution of word knowledge to comprehension of print and speech as a consequence of two premises: first, mappings from print to lexicon are less-practiced than those from speech to lexicon; second, the print signal is inherently weaker than the speech signal as it is devoid of such information as provided by co-articulation of speech sounds, prosody, non-linguistic context and speaker affect. Our data support this prediction, as shown in Table 4.

A Connectionist Model

What mechanism might be responsible for the observed asymmetric influence of lexical quality? We adopt a connectionist perspective based on the framework first outlined by Seidenberg & McClelland (1989; see also Harm & Seidenberg, 1999; Harm & Seidenberg, 2004; Joanisse & Seidenberg, 2003; Plaut & Shallice, 1993; Plaut, McClelland, Seidenberg, & Patterson, 1996). The model (sketched in Figure 1) treats spoken signals, written signals, and semantic representations as patterns of activation across banks of units. Each unit sends excitatory or inhibitory signals to the units it is connected to (indicated by the arrows in the diagram). The strengths of these weighted connections are developed via a training process; the network is exposed to many examples of desirable behavior (e.g., activating an appropriate set of semantic features in conjunction with the phonologic or orthographic features of a

particular word) and small changes in the weights are made which iteratively improve the model's ability to exhibit coherent behavior (Pearlmutter, 1989,1995;Rumelhart, Hinton, & Williams, 1986).⁵ This training process is analogous to the individual's acquisition of linguistic knowledge through experience.

Two properties of this model are important for the issues at hand. First, the encodings of complex lexical properties are distributed: many units are activated to encode the different properties a word has (orthographic, phonological, semantic, syntactic). Second, some of the connections in the model are recurrent; the connections form loops so that activation can cycle around repeatedly within some banks of units as well as between some banks of units. These two properties, in conjunction with the training regimen, imply that features occurring together (in training/experience) will tend to reinforce each other. Therefore, when some features of a word become active (phonological features, for example, by way of speech input) then the network will tend to turn on other features associated with that word (e.g., its semantic features), ultimately leading to activation of enough features for a word as a whole to be usefully accessible.

Lexical access, in such a connectionist model, can be visualized as movement over dimpled landscapes, like those depicted in Figure 2 (Harm and Seidenberg, 2004). Points on the landscape correspond to states of the model (which, in turn, are analogues of mental states). The dimples, or basins, in the landscape correspond to word senses. Initially, when few of a word's features are active, the model is near the rim of a basin. Subsequently, when activation spreads from the initially activated features to other features of the word, we can think of the model state as sliding down the side of the basin and eventually coming to rest at the bottom. This bottom-of-the-basin state corresponds to the network's interpretation of the word, given the representation at hand. We assume, as is standard in such models, that small-magnitude noise in the unit activations disturbs the process of gravitating into the basins, sometimes producing erroneous categorizations.

This type of system includes a straightforward mechanism for modeling both within- and between-subject variation in quality of word knowledge. High quality lexical representations are those with well-tuned connections among features, corresponding to deep basins with steep sides. So, within the lexicon of the individual depicted in 2A, the right-hand basin corresponds to a better quality lexical representation than the left. Each individual has a landscape of basins, one for each of the word senses they know; thus variation between individuals is modeled as contrast in the shapes of corresponding basins (e.g., the left-hand lexeme in reader 2A's lexicon is less well developed than the corresponding lexeme in reader 2B's). This model thus offers an explicit implementation of what Perfetti and Hart (2002) call the "functional identifiability of words".

Because people hear and use spoken language so extensively from an early age, the connections mediating the relationships between speech input, phonological representations and semantic representations are well developed by adulthood. The speech modality thus strongly supports language interpretation. On the other hand, most young adults have less experience with print than with speech. There is also considerable variation in experience with print (Stanovich & Cunningham, 1992). Further, print is a relatively impoverished signal vis a vis phonology and prosody. Stress, intonation and coarticulation information are absent. Moreover, the phonological basis of an alphabetic writing system corresponds only approximately to the phonological representations formed on the basis of early experience with speech (Fowler,

⁵This model is a close relative of the "Triangle Model" of lexical representation introduced by Seidenberg & McClelland (1989) and developed in many subsequent papers. The "triangle" of those models corresponds to the Orthographic bank, the Phonological Bank, and the Lexical Representation bank, and the connections between them, in our model.

1991) and there may be variation in how well an orthography maps to each individual's phonological representations due to dialectic variation (Charity, Scarborough, & Griffon, 2004).

These factors, we assume, are root causes of weak connections from Orthographic Input to Phonology and from Orthographic Input to Lexical Representation. Because the activation of word form is more tenuous via the print modality, the activation of word meaning will be weaker as well. Thus, top-down influences on lexical access, specifically, those aspects of word-knowledge that encode syntactic and semantic information, will be more important to comprehension of print than to comprehension of speech.⁶

Consider a reader with rich, well-tuned, connections among the semantic and phonological features of words within the lexicon. Such a reader has an advantage in dealing with the weaker print signal, compared to a reader whose lexical interconnections are impoverished. Strong mutually supporting connections between correlated features within the lexicon allow a word to be activated quickly, even given relatively poor cues from the orthographic channel. On the other hand, a reader whose connections among features are not as rich or finely-tuned will not be able to compensate as well for the weaker cues provided by the orthographic signal. Lexical access will be slower and more laborious. In the context of Figure 2, the system will gravitate more slowly toward the bottom of a basin (corresponding to longer reading times) and have a greater likelihood of being knocked out of the basin by noise (corresponding to arriving at an incorrect meaning, or failing to comprehend at all).

In contrast, differences in quality of lexical representations will have less effect in the spoken modality because the strength of the connections between speech and lexicon compensates for the weakness among semantic interconnections. Thus the model provides an implementation of the notion that top-down cues (from lexical representation) are most important when bottom-up influences (linguistic percept derived from acoustic or visual signal) are at their weakest. We hasten to point out (as also observed by Perfetti & Hart, 2002) that even the lexicon of an individual with generally strong representations, will certainly include many lexical representations that are not of high quality. The converse is also true. A person may have generally weak representations, but their lexicon will certainly include high quality representations for many words. A marginally literate laborer may well have higher quality lexical representations for words that belong to the jargon of his trade than an attorney has for those same words.

Consider the word bough. As a close synonym of branch, its meaning is likely within the common experience of most individuals, even though the former word form may not be as familiar as the latter (based on frequency of occurrence). We maintain that access to a word that is stored in lexical memory, especially a moderately low-frequency word with irregular spelling like bough, may be modulated by the strength of its semantic representation. Because, if a person has a word well-represented in her internal lexicon, she will require a less robust external stimulus, whether in speech or print, to activate that representation to a useful level. In the case of speech perception, the benefit of a strong semantic representation may be superfluous due to the already well-oiled mapping from speech to lexicon. In the print mode, however, the relatively impoverished nature of the signal, exacerbated in the case of a word form that is both low-frequency and orthographically irregular, may receive a boost due to robustly encoded semantics that is especially helpful.

⁶To be clear, we are not suggesting that top down influences on lexical access do not occur in speech, only that such influences are more important to the recovery of lexical information presented by eye. In fact, considerable experimental work confirms the importance of top-down influences on lexical access in comprehension of speech (e.g. Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979).

Perfetti and Hart (2002) note the existence of a number of “threats to lexical quality”. For example, The word bough is confusable because its spelling could potentially trigger another word. One possibility is buff, which has the same rhyme as rough and tough, words that share an orthographic coda with bough and are more frequent. Alternatively, an encounter with bough might trigger the homophonous, bow (as in “a bow to the audience”), or even its homograph, bow (as in “a bow tie”). This web of ambiguities poses additional challenges, and an individual who has a weak lexical representation for bough, will be at disadvantage in apprehending that word (activating the extant representation) relative to someone who has a more robust representation, and especially so in print.

Additional Support for the Lexical Quality Hypothesis

Empirical support for the hypothesis that vocabulary strength supports reading comprehension comes, most critically, from a series of training studies by Beck, McKeown and colleagues. The upshot of these studies is that children who received a regimen of vocabulary training (which included a significant oral component) showed gains in reading comprehension relative to control groups who had been matched with the experimental groups on reading comprehension prior to training (Beck, Perfetti, & McKeown, 1982; McKeown, Beck, Omanson, & Perfetti, 1983). While it is certain that experience with print is an important force behind vocabulary development (Cunningham & Stanovich, 1991; West & Stanovich, 1991; Stanovich & Cunningham, 1992; West et al., 1993), the causal connections between word knowledge and reading are not simple. Other studies from Beck and colleagues show that vocabulary training is especially helpful if a print-based regimen is supplemented with significant interactive and verbal components (Beck & McKeown, 1983; Beck, McKeown, & Omanson, 1987). Our model predicts this enhancement through its emphasis on the importance of coordinated behavior throughout the whole language processing system (not just the print-interfaces).

Evidence for deficient lexical-semantic representations in poor readers comes from a study by Nation and Snowling (1999), who examined semantic priming in lexical decision to speech stimuli. They found that young poor comprehenders (average age about 10 to 11 years) showed a weaker semantic priming effect than did good comprehenders who were matched for age, non-verbal IQ and decoding skill. Specifically, good comprehenders showed priming for semantically related items regardless of whether or not they tended to co-occur in the language. Poor comprehenders, on the other hand, only showed priming for semantically related words when they were also linked through co-occurrence. It seems that, for poor comprehenders, the source of ‘semantic’ priming effects may lie in mere word association rather than true semantic relatedness. If so, this suggests that, in general, poor readers’ lexical-semantic representations tend to be weaker than those of better readers. In another demonstration, Perfetti and Hart (2002), show that more- and less-skilled adult readers differ in the speed at which semantic information becomes available. They required participants to judge semantic relatedness of word-pairs. In cases where confusability was introduced through homophony (knight -- evening versus night -- evening), more-skilled readers show the effect of confusability at shorter latencies than less-skilled readers. Thus, these two studies provide converging evidence for the notion that less-skilled readers have generally lower quality lexical-semantic representations than more skilled readers.

The Lexical Quality Hypothesis allows us to explicate connections between reader skill and oral language use. One prediction is that ability to use oral language to express semantic content should correlate with reading ability. It is well-known that the object naming abilities of young poor readers are often slower and less accurate than those of unimpaired readers (e.g., Denckla & Rudel, 1976). We recognize that at least some of the difficulty is attributable to a phonological deficiency (Katz, 1986). However, the claim that all semantic errors in naming

can be explained by appeal to a phonological limitation is less convincing (e.g., Jared & Seidenberg, 1991; but see, Katz, 1996; Cantwell & Rubin, 1992). Nation, Marshall and Snowling (2001) provide evidence supporting a link between quality of lexical representations and facility of spoken language production. They show that, for many poor readers, underlying semantic weaknesses may be the source of difficulty in object naming.

Finally, it is appropriate to acknowledge limitations of the present study. First, we chose to use a sentence-picture matching task based on a subset of the PIAT-R sentence reading comprehension subtest (Leach, Scarborough & Rescorla, 2003). This contrasts with listening measures based on narrative passages (e.g., Ransby & Swanson, 2003; Cunningham, Stanovich & Wilson, 1990). The use of narrative passages rather than individual sentences may capture some aspects of comprehension that are missed by our measure. However, these tasks are not without limitations of their own. Chief among them is poor reliability. Secondly, there are signs that some of our measures may suffer from partial ceiling effects, as indicated by mean scores within 1.5 standard deviations of the maximum possible. It is obviously desirable to use indices with sufficient scope to capture variability at both ends of the distribution. However, ensuring this is a difficult objective to meet when the target population has a wide-range of variability, as is the case, by design, with the present study. In our on-going research program, we will address these measurement issues, while providing further tests of the hypothesis put forward here.

Summary

Perfetti and Hart's Lexical Quality Hypothesis provides a framework for illuminating specific links among reader skill, oral language use, and word knowledge. While the connections between comprehension in each modality, and the capacities that support comprehension, remain to be fully clarified, our data and other work discussed here support the view that a searching examination of the D and L of Gough and Tunmer's Simple View of Reading is necessary in order to arrive at a better understanding of the cognitive underpinnings of reader skill. In particular, this study supports a corollary of the Lexical Quality Hypothesis suggesting that the role of word knowledge in reading comprehension is not merely an extension of its role in speech comprehension. We believe that a close examination of connections between the capacities that support general language comprehension and reading will prove a fruitful avenue for the further elucidation of reader skill differences and their cognitive foundation.

Regardless, there is appreciable evidence suggesting that both decoding skill and word knowledge are worthy targets of remediation efforts directed toward adult unskilled readers. Further, the significant explanatory force contributed by both components of Gough and Tunmer's Simple Model (Listening Comprehension and Decoding) suggests that both improvement in decoding and improvement in spoken language skills are valuable goals. Vocabulary knowledge seems to be doubly important. Its significance for spoken language understanding is obvious. But, the present study indicates that weakness in word knowledge may compound weaknesses in decoding skill such that readers with poorly developed lexical representations have a disproportionately hard time with printed word identification. This, together with the fact that word identification skill figures prominently in reading comprehension, suggests that efforts directed at vocabulary development might be an especially helpful adjunct to reading instruction for adult poor readers.

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Figure 1.

An activation-based model of orthographic, phonological, and lexical knowledge (cf. Seidenberg & McClelland, 1989, etc.).

Figure 2. Energy landscapes depicting simplified (two word) lexicons. For person A, the word sense on the left has a relatively low-quality encoding. Person B has better quality in the left-hand word sense.

Table 1

Means and Standard Deviations of Measures. N=44 except for Spoonerism Reaction Time (N=41) -- three participants were unable to do that task at all. All time measures are reported in seconds

task	N	mean	SD	Max. Possible
word-reading	44	67.68	5.39	76
...grade equiv.		13.27	4.82	--
pseudohom-acc	44	47.82	7.09	60
pseudohom-rt	44	3.59	0.71	--
nonword-reading	44	27.16	3.03	32
...grade equiv.		10.68	4.62	--
print-sentence-comp	44	33.89	5.81	41
...grade equiv.		9.87	3.14	--
print-passage-comp	44	11.95	2.17	15
reading-speed (wpm)	44	176.50	39.01	--
spelling	44	25.93	6.41	36
spoonerism-acc	44	15.32	4.02	18
spoonerism-rt	41	5.75	3.29	--
expressive-vocab (W ASI)	44	57.48	8.30	84
receptive-vocab (PPVT)	44	172.77	17.56	204
...age equiv.		19.37	4.44	--
speech-sentence-comp	44	34.98	4.53	41
...grade equiv.		10.23	2.55	--
verbal-memory	44	31.91	5.75	42
wasi-matrices	44	27.16	3.18	35
visual-memory	44	4.98	1.41	9
mrt	44	10.50	5.97	40
art	44	7.30	6.33	40
IQ	44	104.89	12.81	--
age	44	20.60	2.28	--
years-education	44	12.52	2.35	--

Table 2

Below the diagonal are simple correlations among measures (correlations of composite measures with their component tasks are boxed). For correlations involving Spoonerism Reaction Time, N=41; for all others, N=44 -- see table 1. Above the diagonal are simple correlations of age-partialled scores (variables 1-20 only). Correlations of composite measures with their components are boxed. $|r| \geq .31$, $p < .05$; $|r| \geq .40$, $p < .01$; $|r| \geq .49$, $p < .001$; $|r| \geq .57$, $p < .0001$; $|r| \geq .63$, $p < .00001$

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1. word-reading		.47	-.42	.66	.69	.55	.69	.53	.63	-.42	.66	.74	.73	.43	.52	.42	.33	.57	.73	.71	.60	.00	.33
2. pseudohom-acc	.54		-.39	.73	.24	.42	.38	.25	.50	-.52	.27	.28	.29	.00	.31	.12	.00	.18	.41	.33	.26	.00	.00
3. pseudohom-rt	-.45	-.42		-.29	-.21	-.19	-.22	-.53	-.51	.24	-.28	-.26	-.28	.00	-.25	-.23	-.20	-.24	-.39	-.35	-.25	.00	.00
4. nonword-reading	.62	.72	-.30		.47	.44	.51	.35	.57	-.52	.36	.40	.40	.00	.41	.14	.00	.27	.47	.41	.33	.00	.14
5. print-sentence-comp	.77	.36	-.27	.44		.59	.88	.44	.26	-.52	.75	.73	.78	.59	.57	.49	.30	.60	.65	.69	.70	.00	.30
6. print-passage-comp	.62	.48	-.24	.45	.66		.91	.30	.18	-.34	.57	.63	.63	.58	.45	.46	.12	.52	.46	.54	.56	.00	.27
7. rcomp-composite	.76	.46	-.28	.49	.91	.91		.41	.24	-.48	.73	.76	.79	.66	.56	.53	.23	.62	.62	.68	.70	.00	.31
8. reading-speed	.61	.34	-.55	.36	.55	.39	.52		.50	-.31	.52	.47	.52	.17	.42	.34	.18	.53	.48	.55	.53	.00	.31
9. spelling	.71	.56	-.53	.55	.46	.32	.43	.58		-.42	.15	.25	.21	.00	.29	.21	.33	.34	.46	.44	.20	.00	.16
10. spoonerism-rt	-.48	-.56	.27	-.53	-.56	-.40	-.53	-.38	-.47		-.45	-.43	-.46	-.23	-.50	-.39	-.25	-.23	-.48	-.39	-.49	.00	.00
11. expressive-vocab	.72	.35	-.33	.37	.78	.63	.77	.58	.30	-.50		.80	.96	.55	.61	.51	.25	.55	.76	.72	.84	.00	.30
12. receptive-vocab	.81	.39	-.31	.38	.82	.69	.83	.57	.46	-.48	.82		.94	.62	.53	.62	.28	.58	.62	.66	.77	.00	.31
13. vocab-composite	.80	.39	-.34	.39	.84	.69	.84	.61	.40	-.51	.95	.95		.61	.60	.59	.28	.60	.73	.73	.85	.00	.32
14. speech-sentence-comp	.56	.15	.00	.00	.70	.64	.74	.32	.25	-.32	.62	.72	.70		.30	.59	.18	.43	.40	.45	.59	.00	.18
15. verbal-memory	.59	.38	-.29	.42	.63	.51	.62	.49	.40	-.54	.66	.60	.66	.41		.49	.34	.38	.47	.47	.61	.00	.29
16. wasi-matrices	.50	.21	-.28	.16	.57	.52	.60	.42	.33	-.44	.57	.67	.65	.65	.54		.58	.36	.45	.45	.72	.00	.27
17. visual-memory	.49	.16	-.26	.00	.49	.27	.42	.33	.49	-.34	.38	.48	.45	.37	.44	.64		.36	.36	.40	.39	.00	.19
18. mrt	.66	.29	-.30	.29	.70	.60	.72	.61	.48	-.32	.63	.69	.69	.55	.47	.46	.51		.66	.90	.50	.00	.32
19. art	.77	.47	-.42	.48	.70	.53	.68	.55	.55	-.52	.79	.68	.77	.50	.53	.51	.47	.71		.92	.67	.00	.33
20. printexp-composite	.77	.41	-.39	.41	.76	.61	.75	.63	.56	-.45	.77	.74	.79	.57	.54	.53	.53	.92	.92		.65	.00	.36
21. IQ	.72	.36	-.32	.37	.80	.66	.80	.60	.36	-.58	.93	.85	.93	.71	.70	.81	.53	.62	.77	.75		.39	.61
22. age	.48	.30	-.19	.10	.58	.36	.51	.38	.47	-.25	.38	.59	.51	.47	.33	.33	.49	.48	.36	.45	.39		.75
23. years-education	.65	.29	-.16	.21	.67	.52	.65	.57	.49	-.27	.56	.69	.65	.51	.52	.50	.53	.64	.58	.66	.61	.75	

Table 3

Simultaneous regression models targeting reading comprehension composite. Unique R^2 is the proportion of variance captured by a given variable after taking into account all other predictors in the model. **Panel A:** Direct test of the Simple View of reading comprehension. **Panel B:** The contribution of Vocabulary

Panel A				
	std. β	t value	p $\leq$	unique R^2
speech-sentence-comp	0.62	7.07	0.00001	0.30
nonword-reading	0.42	5.41	0.00001	0.18
age	0.18	2.02	0.05062	0.02
Multiple R^2 : .76				
Panel B				
	std. β	t value	p $\leq$	unique R^2
speech-sentence-comp	0.38	3.75	0.00058	0.07
nonword-reading	0.29	3.68	0.00071	0.06
vocabulary-composite	0.41	3.59	0.00092	0.06
age	0.10	1.21	0.23220	0.01
Multiple R^2 : .82				

Table 4

Simultaneous regression models assessing the relative contribution of vocabulary to comprehension of print and comprehension of speech. In both models, a Box-Cox power transformation is applied to each comprehension measure. **Panel A:** Model targeting print-sentence-comp shows that vocabulary uniquely predicts a large portion variance in comprehension of print, accounting for contributions of age and listening comprehension. **Panel B:** Model targeting speech-sentence-comp shows that vocabulary predicts little variance in comprehension of speech, accounting for contributions of age and reading comprehension

Panel A				
	std. β	t value	p $\leq$	unique R^2
speech-sentence-comp	0.26	2.25	0.03032	0.03
vocabulary composite	0.60	5.67	0.00001	0.16
age	0.15	1.83	0.07547	0.02
Multiple R^2 : .80				
Panel B				
	std. β	t value	p $\leq$	unique R^2
print-sentence-comp	0.52	2.48	0.01755	0.06
vocabulary composite	0.25	1.27	0.20969	0.02
age	0.05	0.38	0.70778	0.00
Multiple R^2 : .60				

Table 5

Simultaneous regression models targeting vocabulary composite. **Panel A:** verbal memory and print experience are highly significant predictors of word knowledge. **Panel B:** The inclusion of additional measures of experience and memory has little impact on the unique contributions of verbal memory and print experience measures

Panel A				
	std. β	t value	p $\leq$	unique R ²
verbal-memory	0.31	3.07	0.00379	0.07
print-experience	0.56	5.25	0.00001	0.19
age	0.15	1.64	0.10959	0.02
Multiple R ² : .72				
Panel B				
	std. β	t value	p $\leq$	unique R ²
verbal-memory	0.31	2.94	0.00552	0.06
print-experience	0.56	4.61	0.00005	0.15
age	0.15	1.14	0.26152	0.01
years-education	0.05	0.32	0.75118	0.00
visual-memory	-0.08	-0.77	0.44445	0.00
Multiple R ² : .73				