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Perceptual organization, phonological awareness, and reading comprehension in adults with and without learning disabilities

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Abstract It is not clear from research whether, or to what extent, reading comprehension is impaired in adults who have learning disabilities (LD). The influence of perceptual organization (PO) and phonological awareness (PA) on reading comprehension was investigated. PO and PA are cognitive functions that have been examined in previous research for their roles in nonverbal LD and phonological dyslexia, respectively. Nonverbal tests of PO and non-reading tests of PA were administered to a sample of adults with postsecondary education. Approximately two thirds of the sample had previously been diagnosed as having LD. In a multiple regression analysis, tests of PO and PA were used to predict scores for tests of reading comprehension and mechanics. Despite the nonverbal nature of the perceptual organizational test stimuli, PO strongly predicted reading comprehension. Tests of PA predicted decoding and reading speed. Results were interpreted as supporting the hypothesis that integrative processes usually characterized as nonverbal were nonetheless used by readers with and without disabilities to understand text. The study's findings have implications for understanding the reading of adults with learning disabilities, and the nature of reading comprehension in general.

Keywords Adults · Dyslexia · Nonverbal LD · Perceptual organization · Phonological awareness · Reading comprehension

This study investigated the influence of basic cognitive functions on reading in adults with learning disabilities (LD). Deficits in phonological awareness (PA) have been identified as

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the principal factor underlying poor reading in individuals with phonological dyslexia or reading disability, and perceptual organization (PO) has been identified as a core deficit in nonverbal LD. PA refers to the metacognitive awareness of phonological structures such as phonemes, onsets, rimes, and syllables as they are mentally represented in an alphabetic code, as well as the formation and manipulation of these mental representations in working memory (Scarborough & Brady, 2002). Impairments to PA appear to be primary and universal in dyslexia (Pennington, van Orden, Smith, Green, & Haith, 1990), and they differentiate adult readers with dyslexia from those without (Gottardo, Siegel, & Stanovich, 1997; Hatcher, Snowling, & Griffiths, 2002; Ramus et al., 2003). Some consider the relationship between deficits in PA and dyslexia to be causal (Ramus et al., 2003; Stanovich & Siegel, 1994; Wagner & Torgesen, 1987), a view supported by neuroimaging research (Hommet et al., 2009; Shaywitz & Shaywitz, 2005; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000; Temple, 2002).

Clinically, PO has been used to describe a set of visual–spatial processes that once were broadly referred to as performance IQ, and now have been reduced and recast as perceptual reasoning (Wechsler, Coalson, & Raiford, 2008). Such abilities have included nonverbal concept formation, visual memory, mental rotation, and visual–perceptual and visual–motor integration. In cognitive psychology, PO refers to perceptual grouping, in which perceptual experiences are assembled into meaningful wholes (Behrmann & Kimchi, 2003; Weintraub & Mesulam, 1983). Meaning emerges from the perception of interrelationships between discrete components in the gestalt sense—that is, the whole is more than the sum of its constituent parts (Kimchi, 1992). In this study, PO refers to visual–spatial processes and the perception of gestalts. Deficits in PO, in both senses, have been implicated in the academic, cognitive, and behavioral difficulties seen in individuals with nonverbal LD (Forrest, 2004; Gross-Tsur, Shalev, Manor, & Amir, 1995; Humphries, Oram Cardy, Worling, & Peets, 2004; Liddell & Rasmussen, 2005; Mamen, 2007; Myklebust, 1975; Pelletier, Ahmad, & Rourke, 2001).

There is a consensus in the literature that deficits in PA impair word decoding and reading speed in adults with phonological dyslexia (Ben-Dror, Pollatsek, & Scarpati, 1991; Bone, Cirino, Morris, & Morris, 2002; Hatcher et al., 2002; Lesaux, Pearson, & Siegel, 2006). There is debate about whether deficits in PA also impair reading comprehension in these adults (Ransby & Swanson, 2003; Sabatini, 2002). The phonological deficit hypothesis (Stanovich & Siegel, 1994) proposes that deficits in PA which underlie poor word decoding in dyslexia are functionally separate from higher-order cognitive processes like verbal reasoning. Accordingly, some studies find no statistical differences in reading comprehension between adult readers with LD and those without (Mosberg & Johns, 1994; Lesaux et al., 2006; Miller-Shaul, 2005; Weaver, 1993; Wilson & Lesaux, 2001). Others, however, find significantly lower reading comprehension scores for participants with LD (Bell & Perfetti, 1994; Kirby, Silvestri, Allingham, Parrila, & LaFave, 2008; Ransby & Swanson, 2003; Simmons & Singleton, 2000; Tractenberg, 2002).

There is no parallel dispute concerning deficits in PO and poor reading achievement, given a lack of research addressing the question (Volden, 2004; Worling, Humphries, & Tannock, 1999). Visual perceptual deficits have been linked to problems with word recognition and word decoding in LD, although with less consistency than is the case for deficits in PA (Birch & Chase, 2004; Jones, Branigan, & Kelly, 2007; Stein, Talcott, & Walsh, 2000; see Pennington, 2009; Vellutino, Fletcher, Snowling, & Scanlon, 2004, for reviews). Children with nonverbal LD have traditionally been reported to be competent word decoders, regardless of apparent visual perceptual deficits (Myklebust, 1975; Fuerst, Fisk, & Rourke, 1989). It has been proposed, however, that as they progress academically, these individuals experience difficulty with reading comprehension. The conjecture is based largely on clinical observation (Foss, 1991; Moss Thompson, 1985; Tsatsanis & Rourke, 2003) and has not been tested in adults (Volden, 2004). The present study addresses this gap.

Why does research into nonverbal LD exclude reading comprehension?

The often-reported reading comprehension weakness in nonverbal LD has not been investigated empirically. The lack may be due in part to the preeminence of social over academic deficits in these individuals. Differences in social perception, including perception of the self in relation to others and to external situations (Myklebust, 1975) are evident early in the development of children with nonverbal LD. Early reading, however, is typically within normal limits. Comprehension problems may not emerge until interpreting, inferencing, and finding main ideas are regularly needed to understand text (Moss Thompson, 1985; Rourke & Tsatsanis, 1996). On the whole, most research into nonverbal LD concerns psychosocial adjustment and functioning (Forrest, 2004; Rourke, 2000). Problems with skills such as kinaesthetic awareness; left versus right orientation; accurate reaching in coordinate space; perception of part to whole relationships; object recognition; face recognition; and perception, recognition, and completion of patterns that are not easily verbalized have all been documented in nonverbal LD (Cornoldi, Venneri, Marconato, Molin, & Montinari, 2003; Gross-Tsur et al., 1995; Liddell & Rasmussen, 2005; Mamen, 2007; Rourke, 1995). These difficulties interfere with interacting easily with the environment and with other people (Rourke, 1995). In this way, social impairments are more prominent in frequency and impact than are the underlying perceptual processing deficits, which themselves may affect social behavior and academic achievement. Similarly, observations of unusual language production in nonverbal LD are usually framed in terms of pragmatics, or the social, communicative use of language. According to Tsatsanis & Rourke (2003),

> Children with NonVerbal LD give the appearance of being facile with language content; they are verbose, use advanced words, and show well- developed reading skills...these children are observed to use their words as a means to regulate behavior and problem solve...[A]n overreliance on language for mediating behaviors and feelings is also common; disparate events are related by making the connection in words. p. 114–115

Both children and adults with nonverbal LD have been noted to use language for reducing anxiety in conversation, concentrating on maintenance of the interaction rather than on communication (Myklebust, 1975; Palombo, 1993; Tsatsanis & Rourke, 2003). Consequently, research into language comprehension in nonverbal LD has focused on language use in oral discourse (e.g., Worling et al., 1999; Humphries et al., 2004).

An alternative

An alternative interpretation is that difficulties with integrative, simultaneous processes that are usually tested with nonverbal materials may also underlie an inferential activity like reading (Kintsch, 1998), which requires part to whole reasoning, the apprehension of gestalts, and awareness of text structure (Bell, 1991; Oakhill, Cain, & Bryant, 2003;

Johnston, Barnes, & Desrochers, 2008; Kintsch, 1998). Some theories frame a connection between nonverbal processing and reading comprehension in imagery. Dual Coding Theory proposes separate verbal and nonverbal systems of mental representation in which language, objects, and events are coded. These representations retain a visual, auditory, haptic, or motor aspect of the initial event or experience. On this view, the connection to PO is asserted at the word level through imaging concrete terms. There is also a link at the metacognitive level in traces of non-linguistic experience that remain in mental representations of text (Sadoski & Paivio, 2001). Similarly, Kintsch's situation models, or multidimensional mental representations of propositional textbases, extend beyond the verbal domain and may include visual and spatial imagery.

It is possible, however, that a link between perceptual organizational functions and reading comprehension does not exist in imagery alone. In support of this alternative, separate and ongoing streams of experimental neuropsychological research were considered together. First, neuroimaging studies have supported the hypothesis that phonological and perceptual organizational processes are lateralized to the left and right cerebral hemispheres, respectively. This research has been extended to individuals with phonological dyslexia and nonverbal LD. A variety of techniques that image neural activity have found neural correlates of recoding, storage, and temporal grouping of phonological material in discrete, primarily left cerebral hemisphere regions (for reviews, see Temple, 2002; Zatorre, 2003). Critically, the neurological responses to phonological assembly and phonemic fluency tests differed in control participants and readers with dyslexia. Less activity in a specific left hemisphere region and anomalous right hemisphere activity has been seen in the latter group (Brunswick, McCrory, Price, Frith, & Frith, 1999; Henson, Burgess, & Frith, 2000; Paulesu et al., 1996; Richards, 2001; Simos et al., 2000). Similarly, electroencephalography and computerized tomography scans have found atypical right hemisphere patterns of activation in participants who demonstrate deficits in PO. These were individuals with diagnoses of nonverbal, or right hemisphere, LD (Dool, Stelmack, & Rourke, 1993; Mattson, Sheer, & Fletcher, 1992; Nichelli & Venneri, 1995; Voeller, 1986). The common motivation for the latter studies was that the neural correlates of deficient perceptual processing in nonverbal LD have been demonstrated as more right than left hemisphere-based (Atchley & Atchley, 1998; Cipolotti, Robinson, Blair, & Frith, 1999; Corballis, 1997; Chabris & Kosslyn, 1998).

Second, more recent studies have suggested that right hemisphere functions contribute to language abilities to a greater extent than research into lateralized cognitive abilities has traditionally concluded (Dien, 2009; Ferstl, Neumann, Bogler, & von Cramon, 2008; Paivio, 2005). For example, increased right hemisphere activation was recorded in a study of college students solving word problems that demanded the integration of unfamiliar semantic associations (Bowden & Jung-Beeman, 2003). In the same population, tasks requiring the extraction and integration of themes from paragraphs (St George, Kutas, Martinez, & Sereno, 1999) and the integration of moderately related sentences (Mason & Just, 2004) produced notable right hemisphere activity. The latter study found equivalent activation in the right and left hemispheres for a purely linguistic task, despite the fact that the test stimuli did not include overtly spatial content (Mason & Just, 2004; see also Faust & Kahana, 2002; Lindell, 2006; Virtue, Parrish, & Jung-Beeman, 2008; for a recent review, see Ferstl et al., 2008).

The suggestion in the present study is that right hemisphere functions may be applied to language processing in addition to visual perception. As Tversky (2006) points out, mental representations derive from perceptual experience but may be manipulated in the absence of physical stimuli (e.g., imagery). Thus, “it is not unreasonable to propose that grouping and other perceptual organizing principles are general processes of the mind, not limited to perception" (p. 155). It is in this sense that right hemisphere dominant operations such as holistic organization of representations (Corballis, 1997; Naglieri & Kaufman, 2001) and the active integration of present information to make the past cohere (Dien, 2009) are proposed to contribute to understanding texts. In that event, just as left hemisphere deficits associated with phonological dyslexia impair word decoding and reading speed, right hemisphere deficits associated with nonverbal LD may impair reading comprehension.

Methodological differences

In addition to the inclusion of perceptual organizational measures to predict reading comprehension, there were other differences in the present study's methodology from the research that has already been cited. Studies finding poor reading comprehension in adult readers with LD have used timed reading tests (Bell & Perfetti, 1994; Gottardo et al., 1997; Kirby et al., 2008). Lower achievement scores for adults with LD found in these studies may have been due to slow reading, with poor comprehension as a secondary effect. In the present study, outcome variables were untimed in order that scores for reading comprehension would be unconfounded by reading speed.

Many adult reading studies have formed single LD groups defined by deficits in phonological awareness, phonological memory, and word decoding (Atchley, Story, & Buchanan, 2001; Gottardo et al., 1997). In such studies, PO has been measured only to determine whether scores fell above a cut-off score as low as the 16th percentile, and PO scores have not been used to further differentiate LD groups. The resulting LD groups have had widely varying perceptual organizational abilities, ruling out a determination of whether poor reading comprehension was related only to deficits in PA. In the present study, perceptual organizational deficits were considered separately from phonological processes, and there were no extreme differences in either PA or PO within any single group.

In addition, here PA was separated from word decoding because the latter skill relies on the former process (Scarborough & Brady, 2002). Similarly, word knowledge contributes to reading comprehension (Braze, Tabor, Shankweiler, & Mencl, 2007; Perfetti, 2007), so Vocabulary was measured separately from the dependent variables. Some reading studies have classified participants in LD groups according to pre-existing individual differences in these skills, including reading comprehension (e.g., Bell & Perfetti, 1994), so that their results were anticipated by variables used to form groups. Here, underlying perceptual processes were tested separately, and in advance of, reading achievement.

Other differences in group assignment involved the use of IQ scores. Given that participants were adults with postsecondary education, it was not necessary to use IQ estimates or index score differences as inclusion or exclusion criteria, nor were these scores used for group classification. Evidence suggests that phonological deficits are independent of IQ (Stanovich & Siegel, 1994; for meta-analyses, see Hoskyn & Swanson, 2000; Stuebing et al., 2002), and on its own, the contrast between verbal and performance IQ accurately identifies only 27% of children with nonverbal LD (Pelletier et al., 2001). Generally, all of these methodological choices were made to isolate perceptual processes from each other and from their consequences. Thus, the following hypotheses could be tested without such factors affecting relationships between PA, PO, and reading achievement.

Hypotheses

The primary hypothesis in this study was that PO mediates reading comprehension independently of PA. Nonverbal tests of PO were administered, avoiding the possible confounding effects of reading experience and verbal ability on the performance of adults with postsecondary education. It was hypothesized as well that PA mediates decoding independently of PO. Tests of PA that did not require decoding were administered to participants, approximately two thirds of whom had been diagnosed as having LD by independent practitioners. Multiple regression analysis estimated the variance in reading achievement that was attributable to perceptual organizational and phonological component scores, which were obtained via principal components analysis. Participants were grouped according to their scores on these perceptual processing components, with the standardized sample means serving as cut-off scores. The question of whether groups' strengths and weaknesses in processing component scores would correspond to group differences in reading achievement was addressed through analyses of variance.

Two hypotheses were tested: (1a) scores on tests of PA but not PO would predict unique variance in decoding, and in reading speed (1b) scores on tests of PO but not PA would predict unique variance in reading comprehension in all participants, with and without cognitive processing deficits, and (2) groups established with the use of perceptual processing tests would differ significantly in reading achievement.

Method

Participants

The study took place at a university in a mid-sized Canadian city with an enrollment of approximately 30,000 full- and part-time students. Recruitment efforts and study procedures were approved by an ethical review committee. To ensure the inclusion of participants with LD-related processing deficits, all of the students with a diagnosis of LD who were registered with the university's disability services office (N=380) were telephoned by office staff and invited to participate. Not all participants were current students. Five staff members with postsecondary education volunteered, and were recruited to include older participants without prior diagnoses of LD. Otherwise, participants with LD-related processing deficits may have been older on average than those without, as a number of students with LD diagnoses who were over the age of 35 volunteered at the outset. Full data sets were collected for 49 adults, who were paid $20 for their participation. Exclusion criteria included acquired brain injury, active clinical depression or anxiety, chronic pain, seizure disorders, and other psychological and medical conditions with the potential to affect auditory working memory (Waters & Caplan, 1996), as indicated on a screening survey. Participants who spoke English as a second language were excluded as well. A diagnosis of attention-deficit/hyperactivity disorder (ADHD) did not prevent participation in this study. In order to reduce the potential impact of attention deficits, two testing sessions were scheduled, and all participants were instructed that they could take rest breaks between tests as necessary.

Procedure and materials

Two data collection sessions were scheduled. The purpose of the first was to review screening information and to gather data for four processing tests and a test of vocabulary.

Reading tests were administered in the second session. Data collection sessions were completed in approximately 1 h each by most participants, including their occasional use of rest breaks. In the first session, participants completed two tests of PA: (a) a Non-word Span task adapted from similar measures (Hulme, Maughan, & Brown, 1991; Snowling, Nation, Moxham, Gallagher, & Frith, 1997) and (b) Spoonerisms (Brunswick et al., 1999; Ramus et al., 2003). Tests to measure PO were (a) the Block Design subtest of the Wechsler Adult Intelligence Scale, third edition (WAIS III; Wechsler, 1997), and (b) Gestalt Closure (Kaufman & Kaufman, 1994). The Vocabulary subtest of the WAIS III (Wechsler) was administered as well. Reading achievement tests completed in the second session were (a) the Reading Speed subtest of Form H of the Nelson–Denny Reading Test (Brown, Fishco, & Hanna, 1993); (b) the Word Attack subtest of the Woodcock Johnson Tests of Achievement, third edition (Woodcock, McGrew, & Mather, 2001); (c) a figurative language measure devised by the researchers after the Figurative Language subtest of the Test of Reading Comprehension (Brown, Hammill, & Wiederholt, 1986); and (d) the Reading Comprehension subtest of the Scholastic Abilities Test for Adults (SATA; Bryant, Patton, & Dunn, 1991). Each variable is described in more detail below.

Non-word Span This test is a measure of pseudoword repetition and memory that relies on phoneme identification. Participants listened to and were asked to reproduce sets of non-words read aloud by the researcher. Sets increased in length from one to six syllables. Participants repeated each non-word immediately after it was presented. Items were adapted from two sources (Hulme et al., 1991; Snowling et al., 1997). Scores were based on the number of consecutive syllables pronounced correctly. Reliability was calculated with Guttman's split-half reliability, which is more tolerant of unequal variances between two forms than is Cronbach's alpha (Garson, 2009). This choice was made because of the higher degree of variability in decoding measures that a sample with participants with phonological impairments would be expected to produce. The resulting split-half reliability score was 0.70. The relationship between inefficient processing of non-words and dyslexia has been well-documented and supported (Ramus et al., 2003; Shaywitz et al., 2003; Vellutino et al., 2004).

Spoonerisms Spoonerisms is a test of PA that targets onset-rime and syllable awareness and requires phoneme manipulation. Twelve word pairs were read to participants, whose task was to transpose the onset sounds of the two words. For example, "doctor, window" became "woctor, dindow." Responses were to be produced in the same order as the initial pair, so that the onset phonemes, but not the base words, were transposed. All correct responses were non-words. Scores were the number of correctly pronounced pairs of non-words given in the correct order. The Guttman's split-half reliability coefficient was 0.81. The test was drawn from another study of university-educated readers with childhood diagnoses of reading disability, in which participants with dyslexia obtained significantly lower scores than the control participants (Ramus et al., 2003). Its application here was also supported by its use in neural imaging studies. Studies recording cortical activity produced during completion of Spoonerisms have found the same pattern of reduced left-sided activation seen in non-word reading by participants with dyslexia (Brunswick et al., 1999; Paulesu et al., 1996).

Block Design The Block Design subtest of the Wechsler IQ scales tests the ability to recognize and then impose structure on visual images (Groth-Marnat, 2009), and demands spatial visualization and nonverbal concept formation (Wechsler, 1997). Split-half reliability coefficients provided by the technical manual were over 0.88 for adults. In an independent study, there was no difference between Block Design's reliability with a group of adults with cognitive disabilities and reliability coefficients reported in the technical manual for typical adults (Zhu, Tulsky, Price, & Chen, 2001). Block Design has been used extensively and successfully to differentiate research participants with nonverbal LD from those with dyslexia, and those without cognitive disorders (Cornoldi et al., 2003; Pelletier et al., 2001).

Gestalt Closure Gestalt Closure (A. Kaufman & N. Kaufman, 1994) is a visual perceptual test of the relational property of closure, or the tendency to perceive full and meaningful forms from incomplete information (Kimchi, 1992). Participants were shown black, yellow, or black and yellow drawings of objects on a white background. The objects' silhouette and interior details were fragmented, so that the objects to be identified were made up of more than the parts that appeared on the page. Scores were the number of correctly identified pictures out of a total of 25. The technical manual for the battery of tests from which Gestalt Closure was taken reported split-half reliability coefficients from 0.82 to 0.87 for adults (A. Kaufman & N. Kaufman, 1994). This test was chosen to operationalize the ability to organize and interpret stimuli that are difficult to verbalize. In an independent study, Gestalt Closure was the lowest score for a mixed slate of cognitive tests given to children with developmental right hemisphere syndrome, and was significantly lower than the mean for the control group (Gross-Tsur et al., 1995). Developmental right hemisphere syndrome is a similar, if not identical, syndrome to nonverbal LD (Rourke, 1995).

Vocabulary The Vocabulary subtest of the WAIS III was administered as an estimate of word knowledge and indirectly, print exposure (West & Stanovich, 1993). Reliability coefficients for this version of Vocabulary were reported to range from 0.92 to 0.94 in adults (Wechsler, 1997). Twenty-two participants had completed Vocabulary previously; 17 of them had done so within the last 3 years, as adults. These participants agreed to release their scores from files in the disability services office to a separate research file. Five participants who were tested with the children's version, and another 27 who had either incomplete assessments or had never completed the test were administered the WAIS III version of Vocabulary.[1]

Reading Speed Participants were asked to silently read the first passage of Form H of the Nelson–Denny Reading Test (Brown, Fishco, & Hanna, 1993). After 60 s, they indicated to the researcher which line of text they were reading. In other studies of adult readers, Reading Speed has been used with other measures to separate samples into high- and low-competency readers (e.g., Cunningham, Stanovich, & Wilson, 1990; Ofiesh, Mather, & Russell, 2005); its reliability has been reported as moderate in adults (Brown et al., 1993).

Word Attack The Word Attack subtest of the Woodcock Johnson-III Tests of Achievement battery (Woodcock et al., 2001) measures non-word decoding. Participants were instructed to read non-words aloud according to English language phonics conventions. The test

[1] Specific information concerning the influence of re-administration of the WAIS on subtest scores in the longer term is lacking in typical adults, and in those with LD (Groth-Marnat, 2009). As a consequence, clinical standards concerning the necessity for current information versus practice effects and the stability of adult cognitive profiles (Association on Higher Education and Disability, 2009; Learning Disabilities Association of Ontario, 2003) guided the decision not to re-administer Block Design or Vocabulary when scores were less than 3 years old.

consisted of two practice items and 32 non-words presented visually in groups of six and seven. Scoring decisions were all or none and were based on the first response produced. There was no time limit imposed. The Woodcock Johnson technical manual (2001) has reported split-half reliabilities of 0.81 to 0.97 for this test. Word Attack was used because of the persistence of weak non-word reading in adults with LD (Bone et al., 2002; Bruck, 1990; Ramus et al., 2003; Shaywitz et al., 2003). The use of non-words reduces the impact of differences in reading experience and word knowledge on word reading results (Olson, Forsberg, Wise, & Rack, 1994).

Figurative Language Tests of figurative language evaluate the ability to interpret non-literal phrases in context through the integration of two dissimilar objects or ideas. The present version was adapted from the Test of Reading Comprehension (Brown, Hammill, & Wiederholt, 1986), a test with norms for children and adolescents. No commercial tests of figurative language designed for adults were found. Given that the participants in the present study were well-educated adults, new items based on phrases used in another study of reading in postsecondary students were written by the researchers (Nippold & Duthie, 2003). Participants read a scenario (e.g., Two people talk about a friend who says very little) and an accompanying figurative phrase (Still waters run deep), and provided an interpretation, using the context as a guide if the phrase was unfamiliar to them. Participants were also asked to choose a figurative expression that most closely matched the meaning of the original expression from one of four additional phrases. The correct response had to be figurative and could have been used in place of the original phrase in the accompanying scenario. There were four options with designated relationships to the original phrase: opposite in meaning (She's a bit shallow), a literal translation (Big rivers run slowly), unrelated in meaning (The meek shall inherit the earth), or the correct, metaphorical answer (There's more to her than meets the eye). Items were administered and scored in the same manner as the commercial test. Guttman's split-half reliability was 0.78. Poor apprehension of figurative language in social discourse has been reported in nonverbal LD, particularly by those who have noted the similarity of language use in nonverbal LD to language impairments seen in patients with brain injuries localized to the right hemisphere (Myklebust, 1975; Rourke & Tsatsanis, 1996).

SATA Reading Test In this test of reading comprehension designed for adults, participants read ten short passages on a variety of topics and answered six multiple choice questions for each passage. Readers had to (a) choose a phrase to summarize the passage’s main idea, (b) interpret vocabulary in context, (c) accurately pull factual information from the passage (two questions of this type per passage), (d) make inferences, and (e) retrieve previously learned knowledge about each topic, if possible. In the present study, participants were told that they could read aloud, make notes, highlight words on the test paper, and use whatever other strategies they would normally use to complete multiple choice tests. There was no time limit. Participants' scores were the number of correct answers out of a total of 60. The technical manual for the SATA reported a Reading Comprehension test–retest reliability coefficient of 0.71 after a 1-week interval. The demographics of the standardization group (n=1,005) were reported to be representative of American adults in terms of age, ethnic background, and socioeconomic status; level of education was not reported. Inter-item reliability coefficients for the age groups represented in the current sample ranged from 0.88 to 0.95. This test was chosen over the Nelson–Denny Reading Test as a measure of reading comprehension because the SATA has more inferential items, and its difficulty level may be more suitable for postsecondary students (Parker & Benedict, 2002).

Statistical analyses

The research questions were addressed using a series of statistical analyses. First, predictor variables measuring processing, and criterion variables measuring reading were reduced with principal components analyses. Next, the first hypothesis was tested. It stated that (a) scores on tests of PA but not PO would predict unique variance in decoding and reading speed; and (b) scores on tests of PO but not PA would predict unique variance in reading comprehension. Multiple regression analyses were used to estimate the amount of variance contributed by tests of PO and PA to reading measures. The second hypothesis stated that groups established with the use of perceptual processing tests would differ significantly in reading achievement. To test this, participants were assigned to one of four groups according to their scores for the tests of processing. Sample means for these tests were used to divide participants into four groups with distinguishable processing score patterns: all scores above the mean, all scores below the mean, and two groups with opposite strengths and weaknesses in PA and PO. Group reading achievement was compared using analyses of variance.

Results

Data screening, descriptive statistics, and data reduction

Score ranges, distributions, and means were examined, and some transformations were made to the data. One participant had outlying scores for Block Design and Gestalt Closure; when the former scores were combined and standardized, the resulting score was 2.70 units below the mean. This case was removed from further analysis to avoid exaggerating the overall influence of perceptual organizational variables and remove the influence of outlying scores on the group to which the participant would have been assigned. Next, the first two item sets for Non-word Span had no variability, so they were treated as practice items and deleted from the total score. The resulting distribution produced skewness of −0.18 and kurtosis of −0.25, and the scores were standardized. Histograms and normality tests indicated that Spoonerisms had a non-normal distribution, as might be expected in a sample of readers with and without deficits in PA. Scores for Spoonerisms were negatively skewed (−1.65), and kurtosis was just over 3. Scores were cubed to minimize these effects. The resulting distribution had a skewness statistic of −0.49, and kurtosis was reduced to −0.88, allowing standardization of the score. The remainder of the variables were converted directly to z scores to facilitate a comparison of tests with a wide range of possible minimum and maximum raw scores (Table 1). Correlations between the processing tests, the Vocabulary covariate, and the reading achievement tests are reported in Table 2.

Data were reduced with two principal components analyses in order to reduce the probability of a false rejection of the null hypothesis. The first analysis was of the four perceptual processing tests that were the predictor variables, and the second was of the four reading tests that were the outcome variables. In the first analysis, z scores for Block Design, Gestalt Closure, Non-word Span, and Spoonerisms were entered in a principal components analysis with a varimax rotation. Two components resulted, accounting for 48.37% and 30.46% of the variance in scores, for a total of 78.83%. Block Design and Gestalt Closure had loadings of 0.90 and 0.94 on the first component, and −0.17 and −0.001 on the second. Non-word Span and Spoonerisms had loadings of 0.10 and −0.30 on the first, and 0.88 and 0.76 on the second. The first component was labeled Gestalt Formation to describe the main feature of PO shared by Gestalt Closure and Block Design.

Table 1 Descriptive statistics for processing, covariate, and reading variables

Variable	Mean	SD	Min.	Max.	Skewness	Kurtosis
Perceptual processes						
Block Design/66	44.83	12.11	16	65	−0.34	−0.09
Gestalt Closure/25	15.17	4.62	5	24	−0.26	−0.26
Non-word Span/60	37.79	9.91	14	56	−0.18	−0.25
Spoonerisms/12	9.81	2.39	1	12	−1.67	3.14
Covariate						
Vocabulary/66	52.25	8.59	31	65	−0.56	−0.38
Reading achievement						
Reading Speed	28.38	3.04	20	32	−0.95	.31
Word Attack/32	211.73	77.47	104	450	1.45	2.23
Figurative Language/30	15.96	4.35	5	24	−0.49	.20
Reading Comprehension/60	47.63	6.39	28	57	−1.01	.97

/X highest obtainable raw score

The second component was labeled Phonological Manipulation/Memory, reflecting the primary demands of the two PA tests.

Variables entered into the second principal components analysis were *z* scores for tests of Reading Speed, Word Attack, Figurative Language, and the SATA Reading Comprehension test. Two components with eigenvalues greater than one were produced after varimax rotation, accounting for 71.03% of the total variance. The SATA Reading Comprehension Test and Figurative Language loaded strongly onto one component (0.862 and 0.824, respectively) and minimally onto a second (−0.031 and 0.241). Word Attack and Reading Speed had higher loadings for the second component (0.830 and 0.786) than for the first (−0.029 and 0.228, respectively; Table 3). The tests that loaded onto the first component required inferencing, semantic flexibility, and interpretation, while those that loaded onto

Table 2 Correlations between perceptual processing, covariate, and reading achievement variables

Variables	1	2	3	4	5	6	7	8	9
Perceptual processing									
Block Design	1	0.72**	−0.12	−0.29*	0.10	−0.27	0.16	0.46**	0.51**
Gestalt Closure		1	0.04	−0.25	0.13	−0.12	0.19	0.57**	0.53**
Non-word Span			1	0.37*	0.25	0.44**	0.34*	0.17	0.16
Spoonerisms				1	0.35*	0.64**	0.28	−0.02	−0.09
Covariate									
Vocabulary				1	0.39**	0.41**	0.49**	0.23	
Reading achievement									
Word Attack						1	0.34*	0.12	0.09
NDRT Reading Speed							1	0.35*	0.11
Figurative Language								1	0.46**
SATA Reading Comprehension									1

NDRT Nelson–Denny Reading Test, *SATA* Scholastic Abilities Tests for Adults

*$p<0.05$; **$p<0.01$ (two-tailed test)

Table 3 Component loadings for principal component analysis of reading achievement variables

Variables	Components (% of total variance)	
	Reading Comprehension (43.81%)	Reading Mechanics (27.23%)
SATA Comprehension	0.86	−0.03
Figurative Language	0.82	0.24
WJ Word Attack	−0.03	0.83
NDRT Reading Speed	0.23	0.79

Varimax with Kaiser Normalization. Rotation converged in three iterations

SATA Scholastic Abilities Tests for Adults, *WJ* Woodcock Johnson, *NDRT* Nelson–Denny Reading Test

the second were tests of decoding and reading speed. Accordingly, the reading achievement components were labeled Reading Comprehension and Reading Mechanics.

Question 1a: Does phonological awareness predict reading mechanics?

To test the hypothesis that the PA component would uniquely account for significant variance in the Reading Mechanics component, regression analyses were conducted. The first used Years of Education, Vocabulary, and Phonological Manipulation/Memory, variables that would be expected to account for skill in reading mechanics. The second analysis used the same three predictor variables as the first, and added the PO component. Phonological Manipulation/Memory strongly predicted scores for Reading Mechanics, regardless of whether Gestalt Formation was included in the model: R=0.69, R^2=0.48, F (3,45)=13.60, p<0.001 (three predictors) and R=0.70, R^2=0.49, F (3,45)=10.17, p<0.001 (four predictors). Including Gestalt Formation as a predictor variable had no statistical impact on the results; in either case, the total variance accounted for was approximately 48%. Beta weights for the model with three variables were Phonological Manipulation/Memory=0.58, Vocabulary=0.20, and Years of Education=0.20. With Gestalt Formation entered, beta weights for each of Phonological Manipulation/Memory, Vocabulary, and Years of Education remained within 0.02 of their original values. The beta weight for Gestalt Formation was −0.07, signifying its lack of contribution. Only Phonological Manipulation/Memory made a statistically significant contribution to either model of Reading Mechanics (Table 4).

Table 4 Goodness of fit statistics for two versions of a regression analysis model to predict reading mechanics

Predictor variables	Reading Mechanics	
	Model 1, 3 predictors β (p)	Model 2, 4 predictors β (p)
Phonological Manipulation/Memory	0.58 (<0.001)	0.57 (<0.001)
Vocabulary	0.20 (n.s.)	0.21 (n.s.)
Years of Education	0.20 (n.s.)	0.19 (n.s.)
Gestalt Formation	–	−0.07 (n.s.)
Model Summary	R=0.69, R^2=0.48 F=13.60, p<0.001	R=0.70, R^2=0.49 F=10.18, p<0.001

Question 1b: Does perceptual organization predict reading comprehension?

To provide a conservative test of the hypothesis that the PO component would predict significant variance in reading comprehension, only Vocabulary, Years of Education, and Phonological Manipulation/Memory, variables that are typically used in regression analyses of reading comprehension, were entered first. Most of the variance in Reading Comprehension was attributable to Vocabulary (β=0.43, $p<0.01$), but the overall model was not significant, R=0.38, R^2=0.14, F (3,45)=2.45. Gestalt Formation was added as a fourth and final predictor variable, and this model significantly predicted Reading Comprehension: R=0.76, R^2=0.57, F (3,45)=14.42, $p<0.001$. Adding Gestalt Formation to Vocabulary, Years of Education, and Phonological Manipulation/Memory increased the overall variance accounted for by the model from 14% to 57%. Beta weights for the model with four variables were Phonological Manipulation/Memory=0.02, Years of Education= −0.03, Vocabulary=0.27, and Gestalt Formation=0.67. Only Vocabulary and Gestalt Formation made significant contributions to the four predictor model for Reading Comprehension (Table 5). Figure 1 illustrates the positive linear relationship between Gestalt Formation and Reading Comprehension. The results of a group assignment procedure, described below, are included in the figure.

Group assignment

As a first step in determining how scores for reading achievement might differ across the sample, participants were assigned to groups according to their scores on the Phonological Manipulation/Memory and Gestalt Formation components. An axis that demarcated the borders between four groups was formed using standardized means for both scores. Each quarter was characterized by contrasting patterns of scores (Fig. 2). Other studies have taken a similar approach, except that mathematical computation and word decoding have been used rather than processing components (Shafrir & Siegel, 1994; Swanson & Jerman, 2007). As noted, in the present study, processing scores were substituted for achievement scores to avoid using outcome measures to define groups. This choice was supported by positive correlations between PA and word decoding, and PO and mathematical ability, that have been found in contrasting deficits research (Rourke, 2000; Shafrir & Siegel, 1994), and in research that examines links between academic skills and the underlying cognitive functions used most in carrying them out (Katz, Goldstein, & Beers, 2001).

Table 5 Goodness of fit statistics for two versions of a regression analysis model to predict reading comprehension

Predictor variables	Reading Comprehension	
	Model 1, 3 predictors β (p)	Model 2, 4 predictors β (p)
Phonological Manipulation/Memory	−0.11 (n.s.)	−0.03 (n.s.)
Vocabulary	0.43 (<0.02)	0.27 (<0.03)
Years of Education	−0.11 (n.s.)	0.02 (n.s.)
Gestalt Formation	–	0.67 (<0.001)
Model Summary	R=0.70, R^2=0.49 F=10.18, $p<0.001$	R=0.76, R^2=0.57 F=14.42, $p<0.001$

Fig. 1 Linear relationship between Gestalt Formation and Reading Comprehension components by group

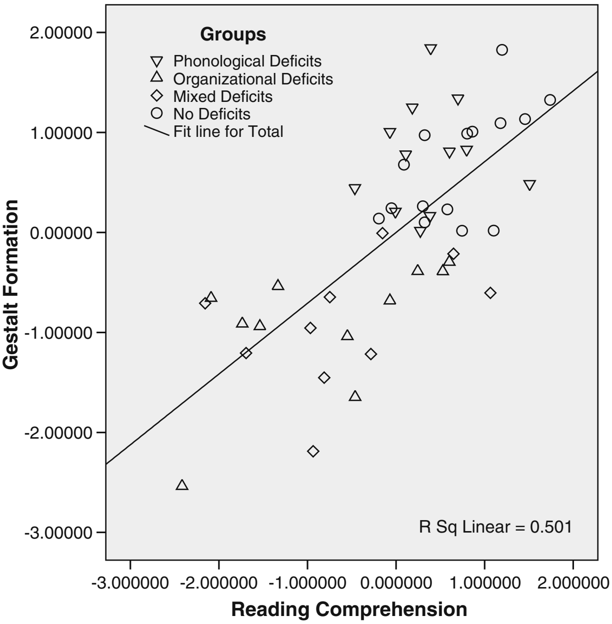
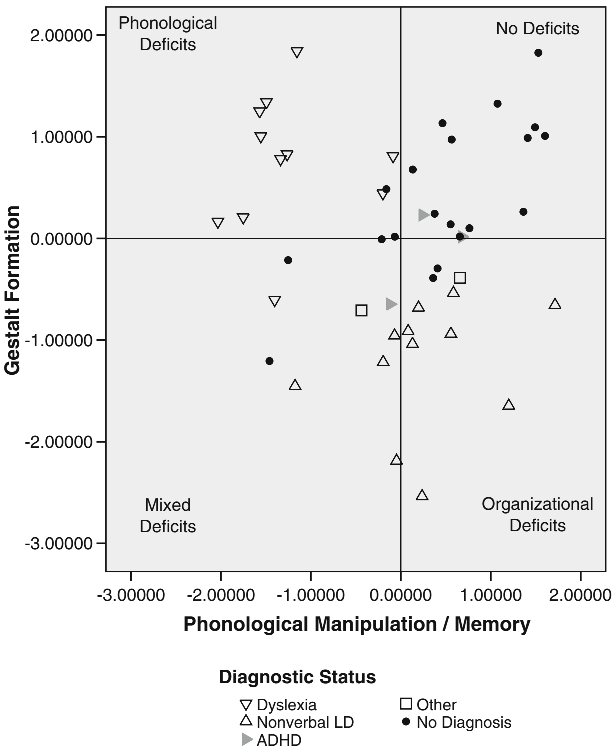


Fig. 2 Participant diagnoses and group membership by mean processing component scores



Participants in the quadrant with scores above the mean for both components were referred to collectively as the no deficits or comparison group. Participants in the quadrant in which scores were at or below the mean for both components were referred to as the mixed deficits group. Gestalt Formation component scores at or above the mean in combination with Phonological Manipulation/Memory scores below the mean characterized the phonological deficits group. Finally, participants with Phonological Manipulation/Memory scores at or above the mean and Gestalt Formation scores below the mean were called the organizational deficits group. Figure 2 depicts groups that were obtained using this technique, in comparison to participants' diagnostic status. The phonological deficits group's pattern of scores was typical of individuals with phonological dyslexia (Von Károlyi, Winner, Gray, & Sherman, 2003; Wilson & Lesaux, 2001), and the majority of group members had been so diagnosed. The organizational deficits group pattern was typical of nonverbal LD (Cornoldi et al., 2003), and again, most group members had the diagnosis confirmed as adults. There was no predominant diagnostic status in the mixed deficits group.

Of the 48 participants, 28 had been assessed for the presence of a disability. Twenty-six of the 28 had been assessed and diagnosed with a learning disability, and two participants recruited as potential comparison participants had been assessed for other purposes. These two students were designated as “other” in Fig. 2 and Table 6. One of the two “other” students reported being assessed for autism because a sibling was affected. This participant had not been diagnosed with autism, but demonstrated processing deficits seen in nonverbal LD. The second of the two students reported having a genetic disorder associated with nonverbal LD (Rourke, 1995), but had not undergone a psychoeducational assessment. This student demonstrated deficits in Phonological Manipulation/Memory and Gestalt Formation. Of the remaining 26 students who had been assessed at some point in their lives, four had been identified as exceptional students when they were children. These four participants had used academic accommodation in elementary or high school but chose not to be reassessed as adults. All four reported being diagnosed

Table 6 Comparison of groups formed by processing scores to participants’ diagnostic status

Group	Diagnostic status				
	Dyslexia	Nonverbal LD	Attention disorder	Other	No diagnosis
Phonological deficits (n=12)					
PM/M≤0	9	–	1[a]	–	2
GF>0					
Organizational deficits (n=11)					
PM/M≥0	–	8	–	1	2
GF<0					
Mixed deficits (n=10)					
PM/M≤0	–	4	1	1	3
GF<0					
No deficits (n=15)					
PM/M≥0	–	1[b]	1	–	13
GF>0					

PM/M Phonological Manipulation/Memory, *GF* Gestalt Formation (processing components)

[a] Dual diagnosis 1: ADHD mixed type/dyslexia

[b] Dual diagnosis 2: ADHD primarily inattentive/nonverbal LD

with dyslexia. The other 22 of the 26 participants with psychoeducational assessments underwent the assessment process as adults, and had childhood diagnoses of dyslexia or nonverbal LD confirmed.

Of the 28 participants in total who had been assessed previously, two were placed in the no deficits group by their processing test scores. Both of these participants had updated diagnoses of ADHD; one was diagnosed with ADHD primarily hyperactive and the other with ADHD inattentive and nonverbal LD. The remaining 26 were placed in one of the three deficits groups.

3Twenty participants had never undergone assessment for a cognitive disability. Seven of these participants were placed by component scores into LD-related processing deficits groups. Their scores for Gestalt Formation and Phonological Manipulation/Memory tended to be close to the sample means, although this was not uniformly the case. Two participants without prior diagnoses in the mixed deficits group demonstrated perceptual processing deficits of the magnitude seen in participants who had been diagnosed with nonverbal LD. In contrast, two other participants without a prior history of LD had phonological scores just under the sample mean, −0.16 and −0.07, which placed them in the phonological deficits group. The mean Phonological Manipulation/Memory component score for the other 10 participants in the group, who had been diagnosed with dyslexia, was −1.244 (SD=0.632). These data are summarized in Table 6.

Overall, groups were reasonably well balanced in a posteriori comparisons of age, enrolled faculty, and years of postsecondary education (Table 7). Given apparent differences in Vocabulary scores, and a reciprocal relationship between the acquisition of word knowledge and PA in adults with LD and without (Acheson, Wells, & MacDonald, 2008; Braze et al., 2007; Sabatini, 2002), group differences in Vocabulary were examined. There was a significant difference in group mean scores for Vocabulary, $F\,(3,44)=4.96$, $p<0.01$. On post hoc analysis, only the difference between the phonological and no deficits group scores was significant, $p<0.01$, with a Cohen's d of −1.23; the other three groups did not differ significantly, although the effect size for the no deficits versus organizational deficits comparison was large, $d=0.98$. Given this result, Vocabulary was used as a covariate in subsequent analyses of variance. The mixed deficits group's mean age was higher than the other groups, but the difference was not statistically significant. The count of their years of postsecondary education, however, was significantly different than the count for other groups, $F\,(3,44)=8.878$, $p<0.001$. The mixed deficits mean was higher than the phonological, organizational, and no deficits group means, $p<0.001$, $p<0.002$, and $p<0.023$ respectively. Nonetheless, using Years of Education as a covariate did not affect the results and was not included in the analyses reported below. Similarly, there were more female than male participants overall, but this difference did not affect outcome variables. Eight of the 48 participants were not Caucasian and were represented in all groups.

Question 2: Are there group differences in reading achievement?

To test the hypothesis that groups would differ significantly in Reading Comprehension, mean group scores were compared with an analysis of variance. The ANOVA for Comprehension was significant, $F\,(3,44)=10.51$, $p<0.001$. On post hoc analysis, significant group differences for the Comprehension component corresponded with group differences on measures of Gestalt Formation (Table 8). The phonological group, consisting of participants with diagnoses of dyslexia, had significantly better scores for Reading Comprehension than did the organizational deficits group, consisting mostly of participants with nonverbal LD ($p<0.03$, $d=1.17$); the comparison of the phonological to the mixed deficits group was not significantly different ($p<0.06$) but produced a large effect size ($d=0.93$). The no deficits group mean was significantly higher than both the organizational ($p<0.005$) and mixed deficits ($p<0.01$)

Table 7 Participant characteristics by group

	Sample total (N=48)	Phonological (n=12)	Organizational (n=11)	Mixed (N=10)	No deficits (n=15)
Sex					
Female	31	7	7	8	9
Male	17	5	4	2	6
Age					
Mean (SD)	26.35 (7.88)	22.81 (4.11)	26.00 (9.02)	29.10 (9.76)	27.60 (7.62)
Range	18–52	18–34	19–46	21–52	19–49
Education					
Mean Years (SD)	3.52 (1.77)	3.00 (1.54)	2.27 (1.01)	5.40[a] (1.58)	3.60 (1.55)
With Accomm.	1.31 (1.53)	1.50 (1.83)	1.27 (1.27)	2.60 (2.88)	0.33[b] (1.05)
Faculty					
Arts	10	3	3	1	3
Graduate Studies	13	2	3	4	4
Sciences	10	2	4	0	4
Social Sciences	15[c]	2	7	2	4
Processing scores					
Phonological	–	−1.06 (0.72)	0.56 (0.50)	−0.64 (0.61)	0.86 (0.51)
Gestalt	–	0.77 (0.54)	−0.91 (0.66)	−0.92 (0.63)	0.67 (0.56)
Vocabulary	52.25 (8.59)	47.33[d] (8.52)	49.18 (71.0)	53.00 (6.59)	57.93 (4.20)
ADHD					
Hyperactive	1	1	0	0	1
Inattentive	1	0	0	0	1
Mixed	2	0	0	1	0

Education years of postsecondary education completed at time of testing, *With Accomm.* years of postsecondary education during which extra time for exams was used, *Graduate* graduate studies or professional school (including Law, Social Work, and Education), *Phonological* Phonological Manipulation/ Memory, *Gestalt* Gestalt Formation, *Vocabulary* raw score for the Vocabulary subtest of WAIS III

[a] Score is significantly higher than scores for all other groups, $p<0.01$

[b] Participants with ADHD reported using extra time for writing exams

[c] Includes four students who reported their faculty as undeclared but whose courses were primarily in Social Sciences

[d] Score is significantly lower than score for the no deficits group, $p<0.05$

groups, with very large effect sizes, $d=1.50$ and $d=1.30$, respectively. The phonological deficits group's mean score for Reading Comprehension was above the sample mean and was not statistically different from that of the no deficits group ($d=-0.33$). The mixed and organizational deficits groups scored below the sample mean. Comparison of these means did not produce a statistically significant difference; the effect size in favor of the mixed deficits group was small, $d=0.25$. These results are depicted in Fig. 3. In a second analysis using Vocabulary as a covariate, estimated marginal means for Reading Comprehension were no deficits=0.51 (0.21), phonological deficits=0.53 (0.23), organizational deficits=−0.70 (0.23), and mixed deficits = −0.63 (0.24). Standard errors are in parentheses.

The phonological deficit group's Reading Mechanics score was significantly lower than the mean scores of the other groups, $F=(3, 44)=12.02$, $p<0.001$. Effect sizes of −1.15, −1.13, and −1.77 for comparisons to the organizational, mixed, and no deficits groups, respectively, were found. Differences between the other three groups were minimal and not statistically significant (Table 8). None of the other groups demonstrated means below zero, regardless of whether the effects of Vocabulary were controlled statistically. The corrected model was significant, F (3,44)=10.25, p<0.001. Estimated marginal means (standard error) for Reading Mechanics were phonological deficits=−0.92 (0.23), no deficits=0.57 (0.21), organizational deficits=0.20 (0.24), and mixed deficits=0.04 (0.23), maintaining group differences regardless of Vocabulary scores. Finally, Reading Speed was examined separately because of the extremely low score for Phonological Manipulation/Memory in one group, which may have obscured differences in speed. Differences were significant, F (3,44)=5.30, p< 0.003. Reading Speed was slow for all three groups characterized by LD-related processing deficits. The no deficits group's reading was faster than the phonological, organizational, and mixed deficits groups, with effect sizes of 1.17, 1.07, and 1.04, respectively.

Discussion

This was the first study to systematically examine the roles of both phonological and perceptual organizational deficits in the reading achievement of adults with postsecondary education. The primary finding was that the PO component, Gestalt Formation, strongly predicted variance in Reading Comprehension. Other key findings were that the PA component, Phonological Manipulation/Memory, predicted significant, unique variance in Reading Mechanics, and that these two relationships (Gestalt Formation with Comprehension and Phonological Manipulation/Memory with Mechanics) were independent of one another. As well, the results were obtained in a sample that included readers without deficits in PA or PO. This finding indicates that the use of PO during reading may be not be unique to readers with dyslexia.

Table 8 Comparison of group means (standard deviations) for comprehension and mechanics reading components

Component	Groups				Comparison	
	Phonological	Organizational	Mixed	No deficits	*p* value	Effect size
Reading Mechanics, mean (SD)	−1.051 (0.086)	0.118 (0.506)	0.055 (0.804)	0.718 (0.220)	PD<ND**	−1.769
					PD<OD*	−1.169
					PD<MD*	−1.106
					ND=OD	0.600
					ND=MD	0.662
					OD=MD	0.063
Reading Comprehension, mean (SD)	0.367 (0.503)	−0.802 (1.07)	−0.604 (0.976)	0.698 (0.569)	PD=ND	−0.331
					PD>OD*	1.169
					PD=MD	0.971
					ND>OD*	1.499
					ND>MD*	1.300
					OD=MD	−0.198

Effect sizes (Cohen's d) were calculated using the pooled standard deviation of the sample. Means and standard deviations are represented in z scores; therefore, effect sizes reflect simple differences between group means

*p<0.01; **p<0.001

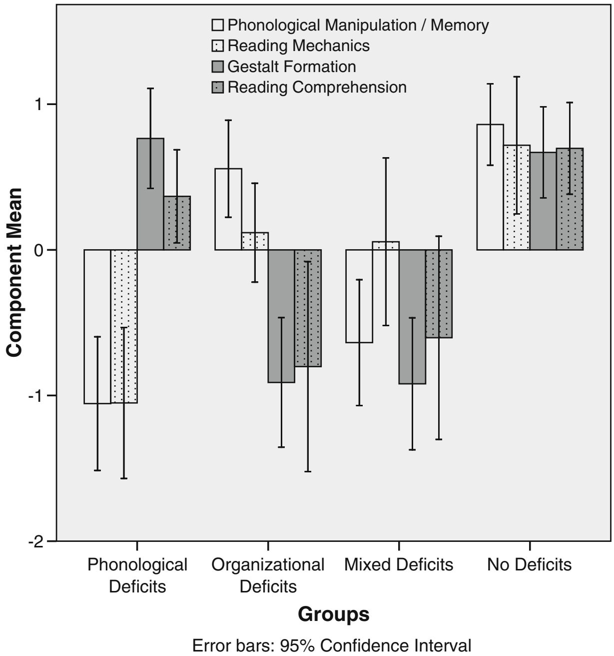


Fig. 3 Processing and reading achievement components, with mean Vocabulary scores, by group

The use of two processing component scores, and four variables in total, to assign participants to groups produced within-group homogeneity that was reflected in significant differences in reading achievement scores. Group assignment was reasonably consistent with the participants' diagnostic status (Fig. 2). In other LD studies, participant groups have been determined in part by achievement scores above or below a cut-off point, for example, the 25th percentile on standardized reading and math tests (Bell & Perfetti, 1994; Shafrir & Siegel, 1994; Swanson & Jerman, 2007). Dividing participants by mean Phonological Manipulation/Memory and Gestalt Formation scores for the sample (Fig. 2) produced groups that were comparable to those found in other studies which used academic achievement scores. Shafrir and Siegel, for example, used the Vocabulary and Block Design subtests of the revised Wechsler scales and two academic achievement tests, one of word decoding and one of arithmetic, to divide a much larger sample of adults with LD. Their Reading Disability group with postsecondary education had higher scores for Block Design than for Vocabulary, as did the phonological deficits group in the present study. The Arithmetic Disability group in the Shafrir and Siegel study showed the reverse pattern of scores, with Vocabulary being somewhat higher than Block Design again in the participants with postsecondary education; this pattern of scores for WAIS III subtests was obtained for the organizational deficits group in the present study (Table 5). Thus, a method that combines the simplicity of Siegel's approach with a focus on the perceptual processes that define the two LD subtypes considered here produced groups similar to those found in other contrasting deficits studies.

Phonological awareness and reading mechanics

Because the relationship between phonology and decoding is a familiar one in studies of LD, it will be discussed first. The prediction of the Reading Mechanics component by the Phonological Manipulation/Memory component was expected, given that reading speed and word decoding are linked conceptually. Poor decoding slows reading, and both are functional limitations associated with underlying phonological deficits. Empirically, impaired word decoding and slow reading appear consistently in readers with dyslexia (for reviews, see Pennington, 2009; Vellutino et al., 2004). The results replicate previous findings that deficits in PA continue into adulthood (Agnew, Dorn, & Eden, 2004; Shaywitz et al., 2003), even in well-educated readers (Braze et al., 2007; Bruck, 1990; Hatcher et al., 2002; Kirby et al., 2008; Shafrir & Siegel, 1994), and that reading is slowed as a result (Daniels, 2008; Lefly & Pennington, 1991; Zeffiro & Eden, 2000).

Group results for Reading Mechanics were largely consistent with scores for Phonological Manipulation/Memory (see Fig. 3). The phonological deficits mean group score for Reading Mechanics was below the sample mean and commensurate with its low score for Phonological Manipulation/Memory. The result was consistent with other reports of poor reading mechanics in adults with dyslexia, including those with postsecondary education (Braze et al., 2007; Kirby et al., 2008). The organizational and no deficits groups had scores above the mean for both Phonological Manipulation/Memory and Mechanics, and they were not statistically different. The mean score on the Reading Mechanics component for the organizational deficits groups supported case study reports that PA is usually average or better in readers with the characteristic deficits in PO typical of nonverbal LD.

Only in the mixed deficits group did scores for Phonological Manipulation/Memory and Mechanics diverge. Despite a low mean score for Phonological Manipulation/Memory, the mixed deficits group had a Reading Mechanics score that was slightly above the sample mean, closer to the group's mean score for Vocabulary than its mean score for Phonological Manipulation/Memory. This result suggests that the significant difference in years of education between the phonological and mixed deficits group, and the latter group's relative strength in Vocabulary (Table 5) assisted participants in the mixed deficits group to compensate for weaknesses in phonological skills while they were reading (Fig. 3). For example, some participants reported being aware of similarities between non-words from the Word Attack test (e.g., splicanter), and real words (decanter), and using their knowledge of these words to assist them in pronouncing the non-words they saw. This possibility is supported by the positive correlations between word knowledge and PA found in the studies cited previously, and the significant correlation in the present study between Vocabulary and Word Attack (Table 2).

Reading was slow for all participants identified as having LD-related processing deficits. This is to be expected, particularly in readers with PA deficits who decode words slowly. The fact that the organizational deficits group also read more slowly warrants more investigation. It has been noted in clinical descriptions of individuals with nonverbal LD that they are good decoders. This supposition was supported here by an above mean Phonological Manipulation/Memory component score in a group that included eight participants with confirmed diagnoses of nonverbal LD. It has also been suggested that such individuals have poor reading comprehension, and this was also supported by the results of the present study. As such, it is possible that these participants were aware of their difficulties, and read slowly in anticipation of being asked comprehension questions. All participants were experienced test takers and knew that the purpose of the study was to examine reading comprehension. That the participants without processing deficits did not read as slowly supports the interpretation that participants with processing deficits sacrificed speed for accuracy out of necessity.

The finding that the phonological deficits group was able to compensate for poor decoding and slow reading on the untimed tests that made up the Reading Comprehension component score was interpreted as support for the specificity aspect of the phonological deficit hypothesis of reading disability, which separates lower-order PA from higher-order text comprehension (Stanovich & Siegel, 1994). The finding contradicts the well-documented chain of relationships from phonology to decoding to reading comprehension seen in children (Cutting & Scarborough, 2006), but it is consistent with recent research in high-functioning adults with dyslexia. The usual relationship between deficits in PA and reading comprehension can be explained in children on the basis of impaired accuracy in word identification. In adults, it is attributed to the effort invested in decoding, which overloads working memory and impedes processing (Bell & Perfetti, 1994; Just, Carpenter, & Keller, 1996; Vukovic & Siegel, 2006). With untimed testing, however, the readers in the present study may have been better able to use re-reading and context to improve word decoding accuracy (see also Ben-Dror et al., 1991; Friedman & Miyake, 2004; Lesaux et al., 2006). Under these conditions, the negative impact of inefficient decoding on the limited capacity of auditory working memory may be reduced and hence be less likely to constrain comprehension. Results of recent studies with postsecondary readers with LD support this conjecture. On timed testing, these studies found significant differences in reading comprehension in favor of readers without disabilities. However, no significant differences between readers with and without LD were found when comprehension was scored as the number of items correct out of the items actually attempted in the time permitted, rather than the number of correct answers out of all of the items presented (Corkett & Parrila, 2007; Deacon, Parrila, & Kirby, 2006).

When the statistical influence of Vocabulary was removed from the comparison of group means for Comprehension, the mean for the phonological deficits group was almost identical to that of the no deficits group; that is, the mean Comprehension score for the phonological deficits group would have been the same as that of the no deficits group without the influence of Vocabulary. Instead, there was a small effect size, $d=0.33$, in favor of the no deficits group. This finding is consistent with research that emphasizes the negative impact of impoverished vocabulary acquisition and retention on reading comprehension in adults (Acheson et al., 2008; Bell & Perfetti, 1994; Braze et al., 2007; Grant, Wilson, & Gottardo, 2007; Sabatini, 2002).

Finally, the present results are consistent with brain imaging research into the relationship between decoding and underlying phonological skills in adults. Studies that find atypical patterns of activity in left hemisphere regions in dyslexia have used tasks similar or identical (Spoonerisms; Brunswick et al., 1999) to those used in the present study, in which a group of participants with deficits in both PA and decoding were identified.

Perceptual organization and reading comprehension

The most novel finding in this study was the relationship between the PO component and Reading Comprehension, as illustrated in Fig. 1. On regression analysis, Gestalt Formation and Vocabulary scores contributed significantly to Reading Comprehension, but Phonological Manipulation/Memory did not. The overall dissociation between Phonological Manipulation/Memory and Reading Comprehension was interpreted as being due to the fact that Reading Comprehension tests were untimed, as discussed above. The strong, positive relationship between Gestalt Formation and Reading Comprehension was also obtained across the sample, suggesting that all readers were using perceptual organizational processes as they read. This view is contrary to that of some researchers, who have speculated that readers with deficits in PA use qualitatively different processes to comprehend text as they read (Wilson & Lesaux, 2001). For example, on finding that individuals with dyslexia demonstrated less left cerebral hemisphere activation and increased right hemisphere activity during reading, Galaburda interpreted the finding as "suggesting that linguistic stimuli are treated in part as non-linguistic stimuli by this group" (1993, p. 239). Instead, it is possible that in most readers, some of the cognitive processes underlying reading are organizational in nature, despite the linguistic format of text.

In support of this interpretation, the phonological deficits group's mean untimed Reading Comprehension score was not statistically different from that of the no deficits group, although the former group included all of the participants in the sample who had been previously diagnosed as having dyslexia. Both of these groups demonstrated above mean Gestalt Formation scores. In contrast, individuals with prior diagnoses of nonverbal LD and/or deficits in the aspects of PO tested here understood complex readings less well than would be expected from their academic success: All participants had successfully completed at least two terms of postsecondary education. The organizational and mixed deficits groups, characterized by low Gestalt Formation scores, had lower scores on the Reading Comprehension component than the phonological deficits group, demonstrated by statistical significance in the first case and a large effect size in the second (Table 8). As noted, this relationship between poor reading comprehension and PO deficits in individuals with nonverbal LD has been reported but not previously tested. Language comprehension research is limited in nonverbal LD (Rourke & Tsatsanis, 1996; Volden, 2004), given its classification as a disorder of nonverbal processing. An alternative suggested by the present results is that more fundamental cognitive and perceptual processes underpin text comprehension and, perhaps, social skills. The relationship was particularly striking because although the predictor variables involved no reading, and the criterion variable was based on reading, the two were strongly related.

It might be argued that the relationship between PO and Reading Comprehension across this well-educated sample is less than surprising if the link exists in comprehension itself—that is, scores for Block Design and Gestalt Closure were representative of general intelligence in a group with high achievement. Although it is a logical possibility, this line of reasoning does not provide any information about which cognitive processes influence language comprehension, or how they might do so. In contrast, the results of the present study suggest that the structuring of mental representations of text directly contributes to the emergence of meaning during reading, as discussed in the following section.

Why was PO associated with reading comprehension?

Three alternatives present themselves for conceptualizing this relationship. These alternatives are not mutually exclusive; the last alternative supports the second at a different level of explanation.

Concrete mental imagery At the psychological level, one explanation suggests that concrete mental imagery, akin to sensory perception, underpins both PO and reading comprehension. A family of theories holds that mental representations retain concrete, perceptual aspects of events or experiences as they are encoded (Barsalou, 2008; Garnham & Oakhill, 1996; Johnson-Laird, 1983; Kintsch, 1998; Sadoski & Paivio, 2001). In this view, individuals attain comprehension by constructing mental or situation models of text events during reading. As noted earlier, research supporting Dual Coding Theory finds that retention and comprehension are better for concrete terms, even when other variables such as word frequency are controlled statistically (Sadoski & Paivio, 2001). The view is also supported by evidence that skilled readers visualize and that teaching visualization as a strategy can increase reading comprehension in individuals with and without LD (Chan, Cole, & Morris, 1990; Mastropieri, Scruggs, & Graetz, 2003). Consistent with this theory, here, tests of PO were visual in nature.

This interpretation does not, however, account entirely for the present study's findings. First, in the test of Figurative Language, concrete imagery would have led to misleading, literal responses. For example, “still waters run deep” evokes a mental image of a slow moving, deep river; however, the correct interpretation of the phrase in the context in which it was presented is that the speaker was describing a person, not a body of water. Second, as passages in the SATA Reading Comprehension subtest became more difficult, relationships between key elements became less concrete. For example, concrete nouns in one passage (ribbon and lace) were united by their status as exports rather than their decorative uses. Similarly, trying to image charters and precedents would not have assisted a reader in understanding the relationship between democracy and various types of constitutions. Thus, although a concrete imagery explanation cannot be completely ruled out, we concur with studies which conclude that imagery may be useful to some readers in some reading activities, but it is not fundamental to text comprehension (McCallum & Moore, 1999; Oakhill & Patel, 1991; Walker, Truscott, Gambrell, & Almasi, 1994).

Cognitive processes The primary link between PO and text comprehension was interpreted as occurring in the active organization of mental representations of text. This interpretation more easily allows PO as a contributing factor to text comprehension: A processing explanation unifies seemingly opposite formats and modalities of representation, such as verbal and nonverbal, auditory, and visual. Colored blocks and printed text have little in common, but inserting “organizing” before both blocks and text makes a strong positive correlation between the two more plausible. In a study with individuals who sustained right hemisphere brain injuries, Wapner, Hamby, and Gardner (1981) concluded that “less intimately involved with the traditional building blocks of language, the right hemisphere seems pivotal in the process of extra- or paralinguistic facets of language” (p. 174). A reinterpretation consistent with the results of the present study is to conceptualize a right hemisphere-biased contribution to reading in the capacity to organize or structure those building blocks.

This view is supported by Beeman's suggestion that perceptual organizational processes may contribute to “recognizing, imposing, maintaining, or reorganizing the structure of [language] and its internal representation” (1998, p. 278), and is also compatible with Dual Coding Theory and other modal views of language comprehension. The construction of situation models, for example, requires deeper processing than the representation of textbases, which are successive and propositional in nature. The demand to integrate a textbase with prior knowledge and a reader's intentions, inferences, and abstractions drawn from the text (Kintsch, 1998) suggests a mechanism like the perceptual organization of text units. Organizational and gestalt formation processes would be applied regardless of whether the units are verbal or nonverbal in format. Finally, as noted earlier, this interpretation is supported by Tversky's contention that construction of gestalts is not uniquely perceptual, but may be more broadly conceptualized as a set of general mental processes (2006).

Brain lateralization Neuroimaging studies consistently support the hypothesis that perceptual organizational and phonological processes are lateralized to the right and left cerebral hemispheres, respectively, in a majority of right-handers. Right hemisphere biased functions such as organization and integration of ongoing information into coherent wholes (Dien, 2009), perception of part-to-whole and whole-to-whole relationships, and visuoconstructive abilities have been characterized as holistic and simultaneous (Goldberg & Costa, 1981; Chabris & Kosslyn, 1998). In the present study, these functions were hypothesized to be as applicable to linguistic processes as they are to nonverbal ones. The strong, positive correlation between nonverbal tests of PO and untimed tests of reading comprehension supported this view, as do language impairments documented in adults with brain injuries localized to the right hemisphere (Beeman, 1994; Benowitz, Moya, & Levine, 1990; Brownell, Simpson, Bihrle, Potter, & Gardner, 1990). Consequently, an interpretation of the present study's results at a neuropsychological level of explanation is that the right hemisphere operates in linguistic processing to facilitate integration and construction of mental representations of text.

Limitations

This study has several limitations. Although one purpose of selecting only four tasks to predict outcomes was to lessen the number of tests needed to assign participants to groups, as Shafrir and Siegel (1994) have demonstrated is possible, it is acknowledged that subtyping studies typically administer a broad battery of tests that tap areas such as visual–motor coordination, tactile perception, speed of processing, rapid naming, academic achievement, memory, attention, inhibition, and other executive functions. To balance this lack in part, the potential influence of executive functions such as attention, planning, and monitoring was deliberately minimized during the reading tests. Participants had enough time to read aloud, summarize, monitor their time, re-read, and talk through and revise their answers as necessary. Additionally, this study was based on a sample of volunteers in a university environment. It is probable that the sample does not represent people with LD in general. This limitation is mitigated by the growing number of postsecondary students who have LD. Since the advent in North America of human rights laws mandating equal access to education for individuals with all disabilities, enrollment of students with LD in postsecondary institutions has increased steadily (Kirby, 2007; Mapou, 2004).

Conclusions

In summary, this study was the first to delineate a clear role for perceptual organizational processes in reading comprehension. The results were interpreted as being consistent with the hypothesis that integrative processes usually characterized as nonverbal and right hemisphere-biased were nonetheless used by readers with and without LD to understand text. Reading comprehension in readers with phonological deficits and prior diagnoses of dyslexia was not statistically different than reading comprehension in readers without processing deficits, suggesting that previous correlations between PA and reading comprehension scores in adults were due in part to the use of timed reading tests. With untimed testing, readers with phonological deficits may have time to compensate for their difficulties. The possibility suggested by the results here is that strengths in PO may serve as one means of the compensation. That is, it is possible that PO is as fundamental to reading comprehension during untimed reading as is auditory working memory during timed reading tasks. Further investigations of phonological awareness and reading comprehension should also include the influence of perceptual organization in readers with, and without, LD-related processing deficits.

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