Neuropsychology of Learning Disabilities: The Past and the Future

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Abstract

Over the past 50 years, research on children and adults with learning disabilities has seen significant advances. Neuropsychological research historically focused on the administration of tests sensitive to brain dysfunction to identify putative neural mechanisms underlying learning disabilities that would serve as the basis for treatment. Led by research on classifying and identifying learning disabilities, four pivotal changes in research paradigms have produced a contemporary scientific, interdisciplinary, and international understanding of these disabilities. These changes are (1) the emergence of cognitive science, (2) the development of quantitative and molecular genetics, (3) the advent of noninvasive structural and functional neuroimaging, and (4) experimental trials of interventions focused on improving academic skills and addressing comorbid conditions. Implications for practice indicate a need to move neuropsychological assessment away from a primary focus on systematic, comprehensive assessment of cognitive skills toward more targeted performance-based assessments of academic achievement, comorbid conditions, and intervention response that lead directly to evidence-based treatment plans. Future research will continue to cross disciplinary boundaries to address questions regarding the interaction of neurobiological and contextual variables, the importance of individual differences in treatment response, and an expanded research base on (a) the most severe cases, (b) older people with LDs, and (c) domains of math problem solving, reading comprehension, and written expression.

INTRODUCTION

Learning disabilities (LDs) have been a central focus of neuropsychological research over the past 50 years. At least 18 of the 51 current and past Presidents of the International Neuropsychological Society (INS) published major research articles on LDs. Over this period, major developments in scientific understanding of LDs have had significant

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implications for assessment and intervention. These developments reflect a merger of disciplines and methods embraced by many neuropsychologists who work across the boundaries of disciplines. In this article, we present a brief historical context, summarize major scientific advances, and discuss their implications for practice. The bulk of research has focused on single-word reading difficulties, although research on other domains of LDs has been flourishing.

HISTORICAL CONTEXT

The hypothesis that difficulties learning to read, write, and do math have a neurobiological basis extends to the beginning of the previous century and is intertwined with the history of neurologically-based behavioral difficulties and attention-deficit/hyperactivity disorder (ADHD; Mahone & Denckla, in press). Early case summaries by ophthalmologists described reading difficulties in non-brain injured children as "word blindness" (Hinshelwood, 1895). Orton (1928) used the term "dyslexia" to represent children who struggled to read and spell isolated words, attributed to disordered cerebral dominance for language. Kirk (1963) used the term "learning disabilities" to refer to unexpected difficulties with academic skills secondary to language problems, but differentiated LDs from intellectual disabilities and behavior disorders.

Neuropsychology shares this historical context because 50 years ago assessment of brain-related functions was considered a primary basis for identifying LDs. The origin of the INS in 1967 began a heady period for neuropsychological research. Rourke (1975) emphasized the importance of profile interpretations for inferring brain dysfunction in LDs. Benton (1975) identified eight neuropsychological correlates of reading difficulties, including finger agnosia, right–left confusion, auditory–visual integration (Belmont, Birch, & Belmont, 1968), color naming difficulties based on alexia without agraphia (Geschwind & Fusillo, 1966), and language problems. Denckla and Rudel (1974) developed rapid naming tests partly because of the color naming hypothesis. Benton hypothesized that the evidence pointed to a parietal lobe disorder that may be maturational, but not consistent with a developmental Gerstmann syndrome (Kinsbourne & Warrington, 1963). Satz and Sparrow (1970) tried to reconcile these hypotheses by attributing reading disabilities to a maturational lag in brain development.

Rutter and Yule (1975) summarized epidemiological studies in which they differentiated children with "specific reading retardation" from "general backwards readers" because of a bimodal hump in the distribution of IQ and reading skills, differences in sex ratio, and signs of neurological dysfunction. Aptitude-achievement discrepancy methods for identification emerged and became a basis for public policy around the world. At a NATO-sponsored conference (Benton & Pearl, 1978), Rourke (1978) refuted the maturational lag hypothesis, showing that neuropsychological deficits persisted. Vellutino (1978) argued that reading problems could be attributed to language difficulties, a view which now prevails. Doehring (1978) characterized neuropsychological research on LDs as a "tangled web of behavioral research," criticizing generalization to theories based on group comparisons of single variables in favor of multivariate approaches. This led to subtypes research in which profiles of neuropsychological tests were identified that presumably would lead to better

understanding of the causes of LDs (Rourke, 1985). The impact of subtyping research culminated in research programs that focused on definition and classification and led to fundamental changes in how LDs are defined, de-emphasizing the importance of IQ (Morris & Fletcher, 1988).

TRANSITION: THE INFLUENCE OF COGNITIVE NEUROSCIENCE

Against this background, contemporary cognitive and linguistic sciences emerged as experimental disciplines. The most significant influence on scientific understanding of LDs, other than the differentiation of academic skills and behavioral disorders, was the theory of speech processing as a segmented signal of phonological representations (Liberman Cooper, Shankweiler, & Studdert-Kennedy, 1967) and the subsequent linkage of phonological awareness skills with the development of word recognition skills (Liberman, 1971). Consistent with investigations of Russian (Chirkina & Grigorenko, 2014) and European scientists (Snowling & Hulme, 1994), these concepts revolutionized reading research.

Phonological awareness is a meta-cognitive understanding of the sound structure of speech. To learn to read, young children must link the orthographic patterns of written language to internal structures of speech to access the developing lexical system. Termed the alphabetic principle, this hypothesis has verification across languages that vary in the transparency of orthography and phonology (Ziegler & Goswami, 2005).

These discoveries were important for research on LDs because a specific cognitive skill, phonological awareness, was linked to decoding, a specific academic skill, with the same cognitive correlate explaining success and failure in reading. Academic skills are *dimensional* and represent normal variation in complex traits as opposed to discrete, qualitatively demarcated categories (e.g., Rutter & Yule, 1975). The dimensionality, as well as the complex phenotypic presentation of LDs, makes it difficult to reliably define individual cases into discrete categories (Ellis, 1984).

The differentiation of LDs into academic domains fueled an expansion of the research base from a focus on dyslexia, leading to a body of replicable research on cognitive correlates, and the neurobiological and contextual factors that related to six domains of LDs. Thus, LDs are separated into reading domains that occur at the level of the word (*dyslexia*) and at the level of text (*reading comprehension*). Math problems may be computational (*dyscalculia*) or involve *problem solving*, often word problems. Difficulties with written expression may involve basic skills needed for *transcription* (handwriting and spelling, *dysgraphia*) or for *generating text* in essays and stories. In any of these domains, a problem with a basic skill like word recognition, computation, or transcription will interfere with reading comprehension, math problem solving, or text generation (Pennington & Peterson, 2015). Problems with these more complex skills are linked to domain-general higher-order language and attentional/executive skills that affect oral and written language. Although prototypes of each of these LDs can be clearly exemplified, the presentations are often comorbid, overlapping not only in the academic domains, but also with other disorders, such as ADHD and developmental language disorders (Fletcher et al., in press; Pennington, 2009).

CURRENT STATUS OF RESEARCH

Over the past 25 years, international interdisciplinary research has mapped out relations of academic and cognitive skills, and related comorbidities, and helped establish a basis for effective intervention. In addition, research on brain structure and function and the genetics of LDs has taken advantage of new technologies. This research can be organized according to Figure 1 (Fletcher et al., in press), which shows the relations of academic skills, the primary defining attributes of LDs, with more proximal cognitive correlates, and behavioral traits (e.g., inattention, anxiety, motivation) that moderate the strong associations of cognitive and academic skills. The behavioral traits, such as ADHD, as well as overlapping academic and cognitive problems (e.g., processing speed; Willcutt et al., 2013), account for comorbidity (Pennington, 2006; Willcutt et al., 2010; 2013). More distal neurobiological (neural and genetic) and contextual factors (home environment, instruction) also interact. In the next section, we describe major areas of research that make it possible to build this framework.

Cognitive Correlates

Cognitive skills are systematically and differentially correlated with academic skills in the six domains of LDs. Classification research has shown that IQ is not predictive of LDs, especially in aptitude-achievement methods (Stuebing et al., 2002); other cognitive discrepancies have not been strongly linked to identification or intervention (Elliot & Grigorenko, 2014). In contrast, working memory and processing speed deficits may be shared across different LDs as well as ADHD and help account for comorbidity (McGrath et al., 2011; Willcutt et al., 2010; 2013).

Consistent with early work on phonological awareness, word-level LDs are marked by a conspicuous problem with the ability to phonologically represent written words. Phonological awareness is a strong predictor of success and failure in reading acquisition (Melby-Lervåg, Leyster, & Hulme, 2012). Difficulties with rapid naming of letters and digits are also apparent, leading to the "double deficit" hypothesis in which children are differentiated according to whether they have problems with phonological awareness, rapid naming, or both (Wolf & Bowers, 1999). The focus on rapid naming brought to the forefront the problem of many non–English-speaking children who struggle to develop automaticity and are slow, but not inaccurate readers. In more transparent languages, dyslexia is identified on the basis of timed reading and spelling assessments (Wimmer & Mayringer, 2002). The phonological component is cross-linguistic, but higher for more opaque and lower for more transparent languages (Melby-Lervåg et al., 2012).

In contrast, text level disorders are associated with vocabulary, listening comprehension, and attention/executive functions that lead to difficulty applying strategic knowledge for inferencing, comprehension monitoring, and creating a situation model of what the person is reading (Cain & Barnes, 2017). Specific reading comprehension disabilities are less frequent than word-level disabilities (Leach, Scarborough, & Rescorla, 2003) and more likely in older children, who have mastered word-level skills, often appearing as a late emerging LD (Catts, Compton, Tomblin, & Bridges, 2012). In younger children, reading comprehension is constrained by decoding, which is a stronger predictor of reading comprehension; in older

children, listening comprehension becomes the stronger predictor (Garcia & Cain, 2014). Identifying reading comprehension difficulties depends in part on the age of the child and how comprehension is assessed (Keenan, Betjemann, & Olson, 2008). The key is that, in the absence of a word-level problem, the same cognitive, linguistic, and strategic difficulties are seen in comprehension of oral and written discourse (Stothard & Hulme, 1992).

Some children have isolated word-level problems and no impairments in math, whereas others demonstrate specific math disabilities with no reading difficulties; yet comorbidity is common (Rourke & Finlayson, 1978; Willcutt et al., 2013). Similar to reading, the cognitive correlates vary with the domain of mathematical competency (calculation vs. problem solving) and the specific mathematical process assessed (algebra, fractions) (Geary, 2005). Numerosity is variously defined, but can be understood as the representation of quantity and comparisons of magnitudes, and their symbolic extensions. Its unique relation to mathematics is not as strong as that of phonological awareness to word reading (Chen & Li, 2014). Working memory, attention, and phonological processing are related to LDs in computations and problem-solving, which also overlap. Math problem solving has been less studied than computational skills, but problems are more apparent with broader language and concept formation skills (Fuchs et al., 2008). Math development and instruction is hierarchical; like the relation of decoding to comprehension, basic skills predict more complex skills. Unlike the relation of phonological awareness and word reading, no single cognitive process stands out as a uniquely robust correlate of math LDs. These findings support Geary's (2013) view that mathematics difficulties involve multiple cognitive processes that reflect more generalized cognitive resource difficulties.

Problems with spatial perception and executive functions have long been implicated in neuropsychological research on children with specific computational disabilities, especially if populations of children with congenital brain injury are included, such as spina bifida (Dennis Landry, Barnes, & Fletcher. 2006). This association gave rise to the concept of nonverbal LDs (Rourke, 1989), but whether the nonverbal difficulties are strongly related to math or represent a syndrome has been questioned (Pennington, 2009).

In written expression, transcription problems are related to difficulties with fine motor skills, finger recognition and proprioception, and perceptual-motor skills (Berninger, 2004). Spelling is related to phonological awareness and is usually impaired in those with word level reading disability. For text generation, executive process that affect self-regulation and organization, as well as oral language skills are more involved (Berninger, 2004).

Genetic Factors

The advent of contemporary genetics methods has enormously influenced scientific understanding of LDs. This research takes three forms (Grigorenko, in press): (1) familial patterns, (2) twin studies, and (3) molecular genetics.

In a meta-analysis of familial patterns of reading difficulties, Snowling and Melby-Lervåg (2016) found that if the threshold for dyslexia was placed above the 10th percentile using population norms, prevalence was 53% in children with an affected sibling or parent. If the reading cut point was below the 10th percentile, the prevalence was 34%. In samples with no

family risk, prevalence rates were reduced and aligned more closely with the percentile threshold. Scerri and Schulte-Körne (2010) reported similar familial patterns in international comparisons despite variations in the orthography of the languages.

The seminal paper of DeFries and Fulker (1985) gave rise to statistical methods for studying twins and separating genetic and contextual influences on reading LDs. In a meta-analysis, 41–74% of the variance in reading achievement and up to 90% of the variance in reading-related processes (e.g., phonological awareness) could be attributed to genetic factors (Grigorenko, 2005). Summarizing six international twin studies, Olson, Keenan, Byrne, and Samuelsson (2014) estimated the influence of genetic factors after first grade at 55–83%. Heritability estimates were lower before the onset of reading instruction; the contribution of genetic factors increased shortly after onset of schooling and with age.

Genetic factors interact with contextual factors and are higher at lower levels of reading ability (Hawke, Wadsworth, Olson, & DeFries, 2007) and lower in samples in which: (1) the parents are less educated (Friend, DeFries, & Olson, 2008); (2) there is greater economic disadvantage (Hart et al., 2013); (3) IQ scores are lower (Wadsworth, Olson, & DeFries, 2010); and (4) the affected children attend poorer performing classrooms (Taylor, Roehrig, Soden Hensler, Connor, & Schatschneider, 2010). There are reading-specific (Naples et al., 2009) and shared genetic contributions to multiple LDs and ADHD, which Plomin and Kovas (2005) labeled "generalist genes."

Genome-wide linkage and association studies identify potential candidate genes, but their effects are small unless pooled together into genome-wide polygenic scores (Dudbridge, 2013). Twin research is most consistent with a *common disorder-common variant* model in which poly-genetic inheritance is assumed and multiple genes exert small influences on indicators of reading or math performance. In contrast, in the *common disorder-rare variant* model, single rare variants with a large effect size account for findings from families with multiple, cross-generationally affected individuals. From these two types of studies, numerous candidate loci (i.e., regions of the genome potentially harboring dyslexia-related genes) and a dozen candidate genes for which structural variation may be associated with variation in reading and reading-related traits have been identified (Grigorenko, in press). These studies need expansion to incorporate more ethnic and socioeconomic diversity.

In other LDs, studies are fewer and are largely twin comparisons. Keenan, Betjemann, Wadsworth, DeFries, and Olson (2006) and Tosto et al. (2014) detected substantial genetic influences on both reading comprehension and listening comprehension; word recognition and listening comprehension contributed independent genetic influences on reading comprehension. Reading comprehension and mathematics share more genetic variance than word reading and mathematics (Harlaar, Kovas, Dale, Petrill, & Plomin, 2012). Genetic influences differ and vary with age for math calculation, problem solving, and fluency (Hart, Petrill, Thompson, & Plomin, 2009). Greven, Kovas, Willcutt, Petrill, and Plomin (2014) observed a genetic correlation of math and ADHD that was greater for inattention than for hyperactivity/impulsivity. In written expression, spelling is as heritable as reading (Bates et al., 2004). Heritability estimates are high (Olson et al., 2013) for both sentence composition (0.72) and handwriting (0.79).

Few molecular genetic studies have examined LDs other than dyslexia. Most studies have examined the structural variation in dyslexia candidate genes in association with other LDs or related componential traits. There is evidence that these genes exert influences that are relevant to multiple LDs. A dyslexia-related locus on chromosome 15q has been linked to both spelling and reading (Schulte-Körne, 2001) as well as to short-term memory (Marino et al., 2007). The variation in the locus on 6p is associated not only with the variation in reading-related indicators, but also with indicators of language (Eicher et al., 2014). Two of the candidate genes for dyslexia, *KIAA0319* and *ROBO1*, appear to be relevant for language and mathematics abilities (Mascheretti et al., 2014).

Neural Factors

Significant understanding of the role of the brain in LDs has emerged because of the advent of noninvasive structural and functional neuroimaging. Following initial studies of adults using positron emission tomography (Rumsey et al., 1994) and a small series of postmortem cases (Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985), most studies have focused on dyslexia. The functional neuroimaging research converges in identifying a network of three left hemisphere regions that support proficient reading and are impaired in people with word-level disorders (Figure 2): underactivation of (1) a ventral stream involving the occipital region and posterior temporal lobe (occipitotemporal); (2) a dorsal stream involving the posterior portion of the superior and middle temporal gyri, extending into temporoparietal areas (temporoparietal); and (3) either underactivation or compensatory overactivation of the inferior frontal lobe (Dehaene, 2009; Shaywitz et al., 1998).

Supported by basic research on word recognition and acquired disorders of reading in dual route (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) and connectionist models (Taylor, Rastle, & Davis, 2013), this network does not develop without explicit exposure to print. It is dependent on evolutionarily based networks for language and visual processing that allow the extraction of language from vision (Dehaene, 2009; Seidenberg, 2017). The dorsal system is associated with a sublexical route to word meaning, consistent with the key role of phonological awareness and word reading. However, also critical is the reorganization of ventral systems that serve face and object processing into regions highly specialized for rapid visual processing of orthographic patterns in print (Vogel, Petersen, & Schlaggar, 2014). The fusiform gyrus has been conceptualized as a "word form" area that mediates immediate word recognition with direct access to semantic regions in the inferior temporal lobes (Dehaene, 2009). Remarkably, this network appears to be universal across different languages and orthographies (Paulesu et al., 2001).

Findings are less consistent from structural than functional imaging studies because of smaller samples and variations in methods (Schultz et al., 1994). However, the rapid development of semi-automated software for processing structural MRI data is changing this state of affairs, with increasing alignment with fMRI research. The development of the ventral system is heavily dependent on exposure to print. In young children and illiterate adults, this system shows rapid reorganization with explicit instruction in reading (Castro-Caldas, Petersson, Reis, Stone-Elander, & Ingvar, 1998; Dehaene, Cohen, Morais, & Kolinsky, 2015). These factors have led to questions concerning whether word-level

difficulties are products of print deprivation versus intrinsic neural deficiencies. Quantitative analyses of structural MRIs have shown reduced volume and thickness in the neural networks of preschoolers before the onset of formal reading instruction. These children, identified because of family histories, have been followed longitudinally with rough correspondence of structural and functional findings (Clark et al., 2014; Raschle et al., 2017). The future of neuroimaging research lies with the capacity for multi-modal methods that co-register structural and functional modalities, linking with genetic studies associated with brain development, and eventually metabolic studies through spectroscopy (Rae et al., 1998).

For reading comprehension, bilateral activation of areas involving semantic processing in the anterior temporal lobes is a consistent feature of both listening and text comprehension (Ferstl, Neumann, Bogler, & Von Cramon, 2008). Cutting et al. (2013) compared children with reading comprehension LD (RCLD) to groups impaired in word reading and typically developing controls on tasks requiring reading of different kinds of words. In the dorsal and ventral pathways of the reading network, the typically developing and RCLD groups had similar activation patterns that were different from the group with word-level LDs. In contrast, the group with RCLD showed reduced deactivation of the left versus the right angular gyrus and reduced connectivity of the left inferior frontal, left hippocampal, and parahippocampal gyri, suggesting more effort in connecting words and meanings. In a structural MRI study comparing similar groups, Bailey, Hoeft, Aboud, and Cutting (2016) found reduced gray matter in right frontal regions in adolescents with RCLD, consistent with their executive function problems.

Studies of children with math disabilities show atypical brain structure and connectivity in inferior parietal and temporo-parietal white matter (Matejko & Ansari, 2015). Functional neuroimaging studies focus on simple numerical and magnitude processing, demonstrating a fronto-temporal neural network extending to three parietal circuits: inferior parietal, superior parietal, and intraparietal, which mediate different aspects of math proficiency. Involvement of different parts of this network varies depending on demands for verbal, number, and visual coding (Ansari & Lyons, 2016). With age and expertise, activation is reduced and with greater automaticity, there is less reliance on frontal circuits (Rivera, Reiss, Eckert, & Manon, 2005). The network is characterized predominantly by *increased* activity in individuals with math LDs that is different from typically developing children in the degree and timing of activation (Iuculano et al., 2015).

There are few neuroimaging studies of written expression. A meta-analysis (Planton, Jucla, Roux, & Démonet, 2013) of 18 fMRI handwriting studies identified specific regions in the right cerebellum, left frontal superior and middle frontal gyri, and left intraparietal and superior parietal areas. Spelling studies show expected activation of frontal motor and planning regions, with overlap in reading areas involved in processing of orthographic patterns (Richards, Berninger, & Fayol, 2009).

INTERVENTION

The evidence base for interventions for people with LDs is strong, reflecting accumulating evidence from large, randomized controlled trials. In a review of 100 years of reading

research, Scammacca et al. (2016) found that as studies get larger and more rigorous over time, effect sizes tend to diminish. However, even small effect sizes have clinically significant impacts. Intervention outcomes are not strongly related to IQ, economic disadvantage, or race (Morris et al., 2012).

Although a review of specific interventions is beyond the scope of this study (see Fletcher et al., in press; Swanson, Harris, & Graham, 2013), some general principles can be identified. Academic interventions are complex cognitive therapies that involve more than simply encouraging children to engage. For those who are struggling, instruction must be *explicit* (Fuchs, Fuchs, & Vaughn, 2014). This means that the instructor purposefully and intentionally involves the learner in the material to be mastered, with direct explanations, modeling of skills and strategies, and opportunities for supervised practice. For *promotion of automaticity*, speeded practice is better than untimed practice, along with *structured engagement* in authentic experiences that supports practice in reading, math, and writing (Fuchs et al., 2014). *Comprehensive* interventions that incorporate multiple instructional practices are more effective than skill-focused approaches. Thus, children with word-level difficulties need programs than not only teach decoding, but also focus on comprehension and automaticity (Mathes et al., 2005).

Children learn as much about math facts if they systematically practice for a short time within the context of a problem solving approach as they do when taught as an isolated skill (Fuchs et al., 2009). The keys are that the instruction is explicit, *differentiated* according to strengths and weaknesses in the academic domains (Connor, Morrison, Fishman, Schatschneider, & Underwood, 2007), and delivered with sufficient *intensity* relative to the severity of the academic problem (Lovett, Lacerenza, Borden, Frijters, Steinbach, & DePalma, 2000). Most effective interventions also incorporate a *self-regulation* component addressing the attention and organizational difficulties experienced by many with LDs (Graham, McKeown, Kiuhara, & Harris, 2012).

Ineffective interventions involve approaches that are not explicit, often based on constructionist, discovery approaches (Seidenberg, 2017). In addition, instruction must focus on academic content (Pennington, 2009). Interventions that train isolated skills, such as working memory, low level auditory and visual processing, or other non-academic interventions based on training the brain or eyes, do not generalize to the academic domain (Melby-Lervåg, Redick, & Hulme, 2016).

A major question from neurobiological studies is the extent of plasticity in the neural networks that mediate reading and math. There are over 20 studies that pair functional neuroimaging before and after reading intervention, and a few studies in math (Fletcher et al., in press). In reading, studies show significant malleability in children who respond to the intervention, with essentially normalized changes reflecting increased activation of the dorsal and ventral systems depending on the task and (probably) the intervention. These changes are maintained in 1-year follow-ups. After math intervention, there is reduced activation and a generally better organized neural network with a reduction in hyperconnectivity (Iuculano et al., 2015).

These indications of plasticity facilitate interpretation of a fundamental finding from intervention research, which is that better outcomes are associated with earlier intervention. When children are identified with basic reading and math difficulties early in development (before Grade 3), intervention efforts lead to greater automaticity (Fuchs et al., 2008; Lovett et al., in press). With later remedial efforts, automaticity is difficult to achieve (Torgesen et al., 2001), possibly because the ventral systems need considerable explicit exposure to print to process orthographic patterns rapidly (Dehaene, 2009). Without this capacity, the person reads slowly and inefficiently, with excessive attention to word reading, which detracts from accessing the meaning of the text.

IMPLICATIONS FOR PRACTICE

Reflecting 50 years of progress, the utility of neuropsychological evaluations does not come from the capacity to infer cerebral dysfunction (Fletcher & Taylor, 1984). Rather, the utility comes from evaluations by individuals with an interdisciplinary knowledge base that situates the person in the context of development and contextual expectations (Waber, 2010). In returning to Figure 1, the critical areas for assessment are academic skills, behavioral traits, and contextual factors. Whether extensive testing of cognitive processes is useful is hotly debated, with concerns about the value added by such assessments for intervention and identification when academic skills are measured (Burns et al., 2016; Stuebing et al., 2015; see exchange by Fletcher & Miciak, 2017 and Schneider & Kaufman, 2017). By assessing academic skills, behavioral traits, and contextual factors, neuropsychologists will have much of the information needed to identify and develop effective treatment plans for LDs.

It is well-known that static frameworks for identifying and treating LDs lead to unreliability in identifying individuals with LDs (Macmann, Barnett, Lombard, Belton-Kocher, & Sharpe, 1989). An alternative uses a dynamic approach that focuses on intervention response over time and use of additional criteria for identification (low achievement and contextual factors) (Fletcher & Vaughn, 2009). This approach integrates identification with treatment response, which would represent a sequential system in which decision errors can be corrected and intervention after screening is prior-itized over identification (Fuchs & Fuchs, 1998; Macmann et al., 1989).

Assessment of strengths and weaknesses within achievement domains is critical for differentiated instruction, along with evaluation of behavioral factors that interfere with learning, such as ADHD, anxiety, and motivation (Fletcher et al., in press). It is critical that neuropsychologists understand the neurobiological basis of LDs and can differentiate the host of correlated factors that contribute to LDs. But in the end, *the neuropsychologist must be able to understand effective interventions* and prescribe them based on the severity of academic strengths and weaknesses of the child, and the behavioral traits that can interfere with learning, such as ADHD, anxiety, and inadequate instruction.

FUTURE DIRECTIONS

Many issues with LDs involve the need to translate and implement the findings from scientific research into education and to treat LDs as a public health problem that can often be prevented. Unfortunately, science is generally not a primary basis for decision making in

education; political trends, experience, anecdotes, and similar bases for evidence prevail (Seidenberg, 2017). Scientists need to do a better job in translating their research, but in education, the role of science is not established despite significant translational efforts (Shavelson & Towne, 2002).

The research base also needs to expand. One important issue is to understand the basis for individual differences in instructional response. More recent conceptualizations of LDs focus on the child's response to instruction, viewing intractability or persistence as evidence of unexpectedness (Fuchs & Fuchs, 1998; Vellutino et al., 1996). This hypothesis is under active investigation from cognitive, genetic, and neuroimaging perspectives (Fletcher et al., in press).

There is also a need to improve identification and intervention research involving (a) the most severe cases, (b) the older cases, and (c) the more complex academic domains. Identification and intervention in adults with academic difficulties who may not have received intervention is poorly understood (Mapou, 2009). We do not know nearly enough about the neural, genetic, and cognitive bases of LDs in math, reading comprehension, and written expression, especially in inadequate responders. The role of cognitive processes in identification and intervention needs continued empirical research. Greater understanding will emerge through interdisciplinary research that questions what we know in a rigorous, scientific approach and seeks to integrate knowledge across domains. As was the case in the early 1970s, neuropsychologists can participate in this research, question their assumptions, and help change the face of practice in the next 50 years.

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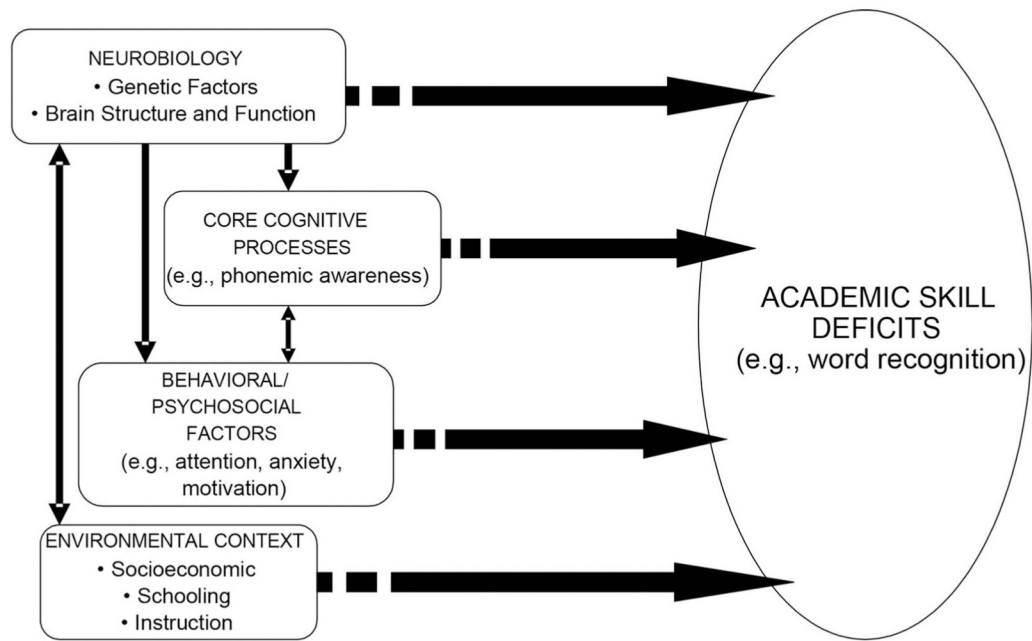
Fig. 1.
Framework representing different sources of variability that influence academic outcomes in children with learning disabilities. Copyright 2007 by Guilford Press. Reprinted with permission from Fletcher, J.M., Lyon, G.R., Fuchs, L.S., and Barnes, M.A. (2007). *Learning disabilities: From identification to intervention.* (1st and 2nd Eds.). New York: Guilford Press, p. 3.
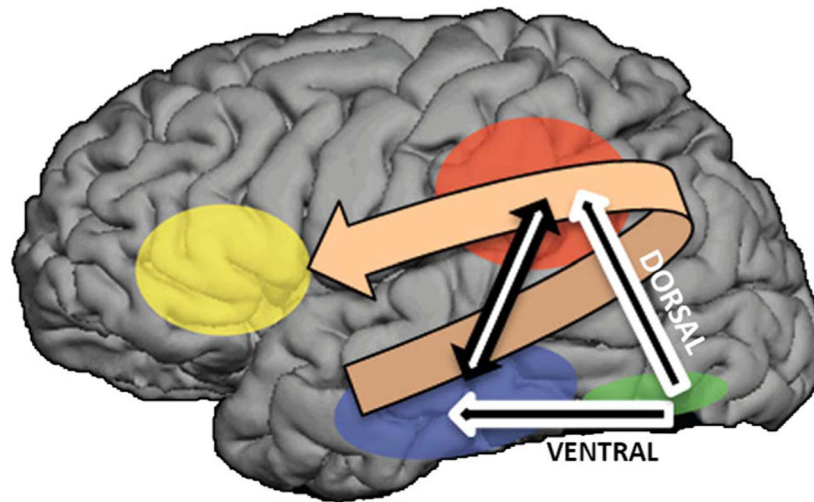
Fig. 2.
Neural network mediating word reading. The sublexical dorsal (temporoparietal) and lexical ventral (temporoparietal) components operate in parallel, connecting to the inferior frontal gyrus if subvocalization or articulation is involved and to the inferior temporal semantic regions for access to meaning. Courtesy Victoria Williams and Whitney Roper.