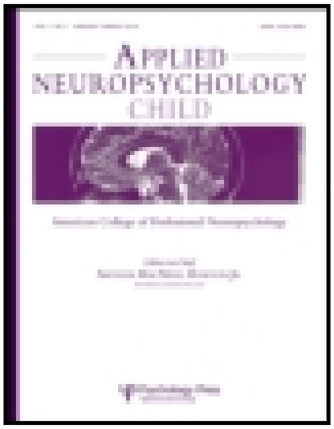

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Neuropsychological Profiles of Written Expression Learning Disabilities Determined by Concordance-Discordance Model Criteria

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Children with specific learning disabilities (SLD) have disparate neuropsychological processing deficits that interfere with academic achievement in spelling, writing fluency, and/or written expression (WE). Although there are multiple potential causes of WE SLD, there is a paucity of research exploring this critical academic skill from a neuropsychological perspective. This study examined the neuropsychological profiles of WE SLD subtypes defined using the concordance-discordance model (C-DM) of SLD identification. Participants were drawn from a sample of 283 children (194 boys, 89 girls) aged 6 years to 16 years old ($M_{age} = 9.58$ years, $SD = 2.29$ years) referred for comprehensive neuropsychological evaluations in school settings and subsequently selected based on C-DM determined spelling, writing fluency, and WE SLD. WE SLD subtypes differed on several psychomotor, memory, and executive function measures (F range = 2.48–5.07, p range = .049 to $<.001$), suggesting that these children exhibit distinct patterns of neuropsychological processing strengths and weaknesses. Findings have relevance for differential diagnosis of WE subtypes, discriminating WE SLD subtypes from low WE achievement, and developing differentiated evidence-based instruction and intervention for children with WE SLD. Limitations and future research will be addressed.

Key words: *neuropsychological processes, specific learning disability, written expression*

A majority of children receiving special education services have a specific learning disability (SLD) classification, with recent estimates suggesting 8% of children have an SLD in one or more academic areas (Boyle et al., 2011). Despite having adequate intellectual functioning, school instruction, and sociocultural experiences, children with SLD present with unexpected academic

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deficits that often adversely impact social, emotional, behavioral, adaptive, and occupational functioning (Backenson et al., 2013; Grigorenko et al., 2013; Silver et al., 2008). Disparate cognitive or neuropsychological processing deficits can lead to different learning deficits among children with SLD, even in the same academic domain (e.g., reading, math, writing; Johnson, Humphrey, Mellard, Woods, & Swanson, 2010; Miller, 2013; Semrud-Clikeman, 2005), suggesting that clinicians need sophisticated diagnostic tools and methods for identifying and supporting children with SLD in written expression (WE) and other areas.

Recognizing SLD: Why Statutory Definitions Should Guide Regulatory Practices

Despite more than four decades of SLD research, clinicians and researchers continue to struggle with how to conceptualize and operationalize the disorder (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012; Hale, Wycoff, & Fiorello, 2010). Although the reductionistic "severe discrepancy" between ability (IQ) and achievement (i.e., ability–achievement discrepancy; AAD) is considered by some to accurately reflect SLD *unexpected underachievement* (Glutting, Watkins, Konold, & McDermott, 2006), the methods used to support global IQ interpretation in disabled populations have been statistically refuted (Hale, Fiorello, Kavanagh, Holdnack, & Aloe, 2007), and most now agree that AAD is largely irrelevant for identifying or serving children with SLD (Elliott, Hale, Fiorello, Dorvil, & Moldovan, 2010; Fletcher, Lyon, Fuchs, & Barnes, 2006; Naglieri & Otero, 2011; Stanovich, 2005). Defining SLD according to "unexpected underachievement" (with AAD as its proxy) disregards the hallmark *processing deficits* that are characteristic of SLD (i.e., statutory definition), ignores the multiple etiologies associated with learning difficulty and SLD, and fails to provide clinical direction for individualized instruction or intervention (Hale, Wycoff et al., 2010; Mather & Tanner, 2014). As Hale, Kaufman, Naglieri, and Kavale (2006) admonish, ignoring this SLD definition is especially problematic given that AAD and rigid cut points to determine SLD are not empirically supported practice.

When the Individuals with Disabilities Education Improvement Act (IDEA; 2004) was first published, AAD was no longer required practice, and instead, a child's failure to respond to evidence-based intervention (Response to Intervention [RTI]) was introduced as an alternate SLD identification method. Although RTI methods have the potential to help many children with learning problems, this "diagnosis by default" model has not been empirically supported for multiple reasons: Different RTI approaches lead to different groups being identified as having SLD, RTI fails to discriminate SLD from low academic achievement or other disorders, and RTI delays needed services for children with SLD (e.g., Barth et al., 2008; Fletcher et al., 2014; Fuchs, Fuchs, & Compton, 2004; Hale, Wycoff et al., 2010; Reynolds & Shaywitz, 2009; Speece, 2005; Waesche, Schatschneider, Maner, Ahmed, & Wagner, 2011).

In light of AAD irrelevance for diagnosis and informing intervention (Fletcher et al., 2006) and the fact that RTI is primarily beneficial for the early identification of learning needs and improving academic outcomes (Burns, Riley-Tillman, & VanDerHeyden, 2013) for nondisabled children, neither of these methods are sufficient for SLD identification. Furthermore, neither AAD nor RTI is supported by legal precedence (as stated by the U.S. and Canadian Supreme Court rulings) requiring comprehensive evaluation in all areas of suspected disability (e.g., Wright, Hale, Backenson, Eusebio, & Dixon, 2013). Thus, combining RTI with comprehensive evaluation of neuropsychological processes may offer the best of both worlds for supporting children who struggle with learning, behavior, and SLD (Hale, Wycoff, et al., 2010)—a perspective shared by many practicing psychologists (Nelson & Machek, 2007).

"Third Method" of SLD Identification: Processing Strengths and Weaknesses Approach

In response to AAD and RTI methodological concerns that emerged soon after the IDEA (2004) was released (e.g., Hale, Naglieri, Kaufman, & Kavale, 2004), the U.S. government's final IDEA regulations (2006) added a *third* SLD identification regulatory method. Hale (2006) operationalized this third method approach by using RTI/assessment methods advocated by educators (Tier 1 standard protocol RTI), school psychologists (Tier 2 problem-solving RTI), and neuropsychologists (Tier 3 comprehensive neuropsychological evaluation). Using this method, Hale, Betts, Morley, and Chambers (2010) showed RTI methods improved gradewide reading and math scores and reduced comprehensive evaluation burden. However, for nonresponders, cognitive hypothesis-testing (CHT; Hale & Fiorello, 2004) neuropsychological evaluations revealed that children had SLD and/or other disorders, and for those with SLD, the reading, math, and/or WE SLD subtype profiles were used to develop targeted, efficacious interventions. Many scholars now conclude that cognitive and neuropsychological assessment of processing strengths and weaknesses (PSW) can help differentiate between SLD, other disorders, and low achievement (Decker, Hale, & Flanagan, 2013; Fletcher-Janzen & Reynolds, 2008; Hale, Alfonso et al., 2010; Mather & Gregg, 2006; Miller, 2013; Naglieri & Otero, 2011; Riccio, Sullivan, & Cohen, 2010; Semrud-Clikeman, 2005).

Documenting a child's PSW, unexpected underachievement, and poor academic treatment response, inherent in modern conceptualizations of SLD (Flanagan, Fiorello, & Ortiz, 2010; Hale et al., 2010; Fletcher-Janzen & Reynolds, 2008), can thus be operationalized in the following SLD definition:

> A specific learning disability is characterized by repeated inadequate response to increasingly intense evidence-based interventions and an inconsistent pattern of cognitive/neuropsychological strengths and weaknesses that lead to insufficient achievement in one or more academic domains.

In this definition, a child who is chronically unresponsive to intervention (i.e., a nonresponder) must also demonstrate a cognitive and/or neuropsychological PSW that leads to poor academic achievement prior to SLD classification. PSW can be based on a growing body of empirical evidence of cognitive process–academic achievement relationships (e.g., McGrew & Wendling, 2010). Phonological, abstract visual-symbolic, rapid automatic naming, memory-encoding, storage, retrieval, receptive/expressive language, visual-spatial processing, fluid reasoning, processing-speed, response inhibition, executive-planning, and working-memory processes have been linked to academic domains and are useful in differentiating SLD from other disorders, SLD subtypes, and/or low achievement according to many peer-reviewed research studies.[1] A PSW approach is supported by cognitive-processing differences between children with SLD and typical peers (Johnson et al., 2010) and by low intellectual functioning (Cornoldi, Giofrè, Orsini, & Pezzuti, 2014). Furthermore, the link between cognitive and neuropsychological functioning and SLD treatment outcome is now regularly being documented.[2] This research suggests that neuromarkers and neuropsychological functioning may predict individual differences or treatment response better than academic performance or observable behavioral measures (e.g., Insel, 2013; Reddy, Weissman, & Hale, 2013; Supekar et al., 2013; Wasserman & Wasserman, 2012).

As a result, the PSW definition presented here is consistent with the IDEA SLD statutory and regulatory requirements (Decker et al., 2013) and ensures that children receive comprehensive evaluations that address all areas of suspected disability, thus facilitating SLD differential diagnosis and intervention development (Hale, Alfonso et al., 2010). Thus, a PSW approach has the potential to provide *differentiated* instruction for children with SLD and other disabilities, a theoretical underpinning consistent with Berninger and Dunn's (2012) emphasis on using neuropsychological and academic data to determine "what works for whom." With the explosion of neuroscientific evidence serving as the impetus for an evolution in psychological practice, clinicians can now use neuropsychological data to more accurately identify child disorders and provide targeted efficacious interventions, thereby linking brain and behavior in the real world.

Operationalizing PSW Approaches for SLD Identification and Intervention

PSW methods and tools differ, but they similarly emphasize: (a) cognitive-processing strengths and weaknesses; (b) academic deficits relative to cognitive strengths; and (c) a theoretical or empirical association between the processing weakness and achievement deficit (Hale, Flanagan, & Naglieri, 2008). For example, the Naglieri consistency-discrepancy approach is based on the planning-attention-sequential-simultaneous model, which has successfully been linked to academic intervention (see Naglieri & Otero, 2011), while the Flanagan aptitude-achievement consistency model is based on well-researched Cattell-Horn-Carroll (CHC) and cross-battery methods (see Flanagan, Ortiz, & Alfonso, 2013; Keith & Reynolds, 2010; McGrew & Wendling, 2010).

The Hale and Fiorello (2004) concordance-discordance model (C-DM) uses a CHC classification of measures for an initial interpretive framework, but also requires a neuropsychological approach (i.e., CHT; Hale & Fiorello, 2004) to ensure the concurrent, ecological, and treatment validity of results (Fiorello, Hale, & Wycoff, 2012). Research investigating C-DM has shown meaningful SLD subtype differences on reading (decoding, fluency, comprehension), mathematics (computation, fluency, word problems), neuropsychological (learning and memory), and psychopathology (rating scale) measures (Backenson et al., 2013; Carmichael, Fraccaro, Miller, & Maricle, 2014; Elliott et al., 2010; Feifer, Gerhardstein Nader, Flanagan, Fitzer, & Hicks, 2014; Hain & Hale, 2010; Hain, Hale, & Glass-Kendorski, 2009; Hale, 2010; Hale, Fiorello et al., 2008; Hale et al. 2013; Kubas et al., 2014). In addition, children with C-DM-identified SLD are more likely to show a positive treatment response when these data are used to guide instruction and intervention (Avtzon, 2012; Hale, Wycoff et al., 2010; Hale et al., 2004; Mascolo, Kaufman, & Hale, 2009; Reddy & Hale, 2007).

Although emerging evidence documents the promise of the C-DM SLD method to guide individualized intervention,[1,2] this empirical work has been limited because most studies did not confirm the processing

[1]The studies that support PSW utility in diagnosing SLD and SLD subtypes and differentiating SLD from low-achievement differences are reported here: http://werklund.ucalgary.ca/braingain/projects.

[2]The studies reviewed that support PSW utility in developing specific interventions for SLD and SLD subtypes are reported here: http://werklund.ucalgary.ca/braingain/projects.

weakness(es) associated with the achievement deficit(s). Given that cognitive/neuropsychological profile difference base rates are high (Decker, Schneider, & Hale, 2011) and that test results do not reliably reflect underlying neuropsychological traits (Koziol, Budding, & Hale, 2013), a more sophisticated C-DM approach is required, such as using CHT to provide the corroborating evidence needed for accurate SLD identification and intervention (Fiorello et al., 2012). In addition, C-DM authors caution against the sole use of psychometric approaches with cutoff scores to determine SLD using any PSW method. Their arguments are bolstered by findings that rigid psychometric PSW SLD approaches lead to good specificity and negative predictive power but limited positive predictive power and sensitivity (Stuebing, Fletcher, Branum-Martin, & Francis, 2012). Therefore, C-DM decision rules can be enhanced by using multiple criteria to confirm PSW (Everatt, Weeks, & Brooks, 2008), as well as the CHT approach to verify or refute initial hypotheses derived from cognitive assessment and other data sources (Fiorello, Flanagan, & Hale, 2014).

Purpose of the Current Study

Previous C-DM research has shown SLD subtype differences in reading, math, psychopathology, and neuropsychological measures; however, there have been no C-DM or PSW studies exploring WE SLD to date. Among academic domains, WE has traditionally been neglected in SLD research, in part because of neuropsychological complexity and measurement difficulties (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008; Hooper et al., 2011). Despite the dearth of WE SLD research, epidemiological research suggests that approximately 6% to 18% of children have a significant WE problem (Katusic, Colligan, Weaver, & Barbaresi, 2009; Mayes & Calhoun, 2006). In addition, although reading, oral language, and WE are neuroanatomically and behaviorally related (Richards et al., 2009), approximately 25% of children with WE SLD do not have reading SLD (Katusic et al., 2009). Four to 11 WE subtypes have been identified in previous studies (Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002; Roid, 1994; Sandler et al., 1992), suggesting WE subtype processing deficits may differentially predict treatment response (Wakely, Hooper, de Kruif, & Swartz, 2006).

Given that a strict psychometric C-DM approach is limited, additional neuropsychological and other data sources are needed to ensure its discriminant validity. The current study was designed to evaluate the C-DM approach for WE SLD identification and to determine whether grouping children with WE SLD into C-DM-determined processing weakness subtypes revealed different patterns of neuropsychological performance on auditory-language-memory, visual-spatial-holistic, motor sequencing-constructional-psychomotor speed, and executive working-memory-interference control-retrieval fluency measures. Examining WE SLD subtype neuropsychological functions could provide clinicians with the supplemental CHT evidence necessary to corroborate initial hypotheses derived from cognitive test profiles, thus increasing WE SLD identification accuracy and intervention effectiveness.

METHOD

Participants and Procedure

Archival data were collected on 283 children (194 boys, 89 girls) aged 6 to 16 years old ($M_{age} = 9.58$ years, $SD = 2.29$ years) from diverse urban and suburban school settings. Licensed neuropsychologists or licensed/certified psychologists with formal neuropsychological assessment training completed neuropsychological evaluations of participants referred for learning and/or behavioral difficulties. Children in this clinical sample were administered cognitive, neuropsychological, academic, and/or behavioral measures according to their suspected area(s) of disability; thus, a flexible neuropsychological test battery (Decker et al., 2013) or CHC cross-battery approach (Flanagan, Ortiz, Alfonso, & Mascolo, 2006) was used. For the present study, the *Wechsler Intelligence Test for Children-Fourth Edition* (WISC-IV; Wechsler, 2003), the *Woodcock-Johnson Tests of Achievement-Third Edition* (WJ-III Ach; Woodcock, McGrew, & Mather, 2007), the *Wide Range Assessment of Memory and Learning-Second Edition* (WRAML-2; Sheslow & Adams, 2003), the *Delis-Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001), and the *Developmental Test of Visual-Motor Integration-Sixth Edition* (VMI-6; Beery & Beery, 2010) measures were included. Children were excluded if they had WISC-IV Full-Scale Standard Scores (i.e., IQ) less than 75 to rule out suspected intellectual disability or evidence of brain trauma, genetic disability, or a medical condition interfering with test performance.

Participants were grouped into SLD subtypes based on presumed cognitive strengths, cognitive weaknesses (WISC-IV), and academic deficits (WJ-III reading, mathematics, and/or WE subtests) determined by a psychometric C-DM approach. The psychometric C-DM approach first compares cognitive strengths to cognitive weaknesses, which were also compared to WJ-III Ach writing subtest scores to determine if each child met C-DM criteria. If a significant difference ($p < .05$) emerged between the cognitive strength score and the cognitive weakness score and between the cognitive strength score and the writing achievement score, the child was identified as having an SLD. If no significant differences emerged between the cognitive strength and the cognitive weakness or between the cognitive strength and any of the academic subtests, the child was not identified as having an SLD.

WISC-IV factor and subtest scores used to define PSW were not confirmed using CHT, nor were there efforts to link PSW patterns to achievement deficits—a practice that would negate C-DM use for individual children (Hale & Fiorello, 2004). The WISC-IV index scores were used for PSW unless there was significant within-factor variability ($p < .05$; Wechsler, 2003). If there were subtest differences, two-subtest combinations were created using the CHC and/or neuropsychological WISC-IV interpretive approach (e.g., Flanagan, Alfonso, Mascolo, & Hale, 2010; McGrew & Wendling, 2010; Miller & Hale, 2008), with averaged subtest means and reliability coefficients used for C-DM calculation. The standard error of the difference formula ($p < .05$; Anastasi & Urbina, 1997) was used to establish PSW.

A no-SLD group ($n = 66$, 23.3%) and five SLD subtypes were identified, including presumed left hemisphere (LH-SLD; auditory-lexical-semantic-crystallized subtest weaknesses; $n = 18$, 6.4%), presumed right hemisphere (RH-SLD; determined by visual-spatial-fluid reasoning subtest weaknesses; $n = 25$, 8.8%), presumed working memory (WM-SLD; determined by auditory sequential-working-memory subtest weaknesses; $n = 46$, 16.3%), presumed processing speed (PS-SLD; determined by processing speed-associative-learning subtest weaknesses; $n = 81$, 28.6%), and executive (EX-SLD; determined by Working Memory Index and Processing Speed Index [PSI] subtest weaknesses; $n = 47$, 16.6%). From this sample, children with C-DM deficits on the WJ-III Spelling, Writing Fluency, and/or Writing Samples subtests were further excluded if they had average WE scores ($SS = 90$ or greater). This ensured that the final sample did not include children with higher cognitive functioning or gifted children with C-DM-determined WE SLD. These criteria addressed an ongoing PSW (also true with AAD) criticism that children with higher cognitive functioning are more likely to be identified with SLD compared with lower-functioning children (Fletcher, Lyon, Fuchs, & Barnes, 2006). Thus, the final sample included children with no SLD in reading, math, or WE ($n = 66$) and children with WE SLD with below-average WE subtest scores ($n = 146$), thereby allowing for direct comparison of children with no SLD to those with WE SLD who also had low WE in at least one area.

RESULTS

The groups differed in the prevalence of WJ-III Spelling, $\chi^2(5) = 135.07$, $p < .001$ ($\varphi = .85$, $p < .001$, $n = 181$), Writing Fluency, $\chi^2(5) = 69.13$, $p < .001$ ($\varphi = .69$, $p < .001$, $n = 144$), and Writing Samples, $\chi^2(5) = 74.32$, $p < .001$ ($\varphi = .59$, $p < .001$, $n = 212$; see Table 1). The C-DM-determined SLD subtypes did not differ for the Spelling analyses, with most children with WE SLD identified as having spelling difficulties regardless of their specific processing weakness. Of note, however, was that every child with WM-SLD was found to have a spelling deficit. In contrast, for the Writing Fluency analysis, primarily the LH-SLD (89%), PS-SLD (77%), and EX-SLD (87%) subtypes had deficits. For the Writing Samples subtest, no meaningful SLD subtype relationships were apparent.

The WISC-IV index and WJ-III WE subtest differences across the no-SLD group and all five SLD subtypes are presented in Table 2, with the WISC-IV subtest differences displayed in Figure 1. Although all analyses were significant (F range = 2.86–21.16, $p < .01$), this would be expected given the strictly psychometric C-DM WE SLD definition in this study. As a result, these data should be interpreted for descriptive rather than inferential purposes. Qualitatively, only the PS-SLD subtype appeared to have an additional processing weakness (PSI), with other subtype weaknesses consistent with their definition. The LH-SLD,

TABLE 1
Children Identified With Concordance-Discordance Written Expression SLD

WJA Subtest	*C-DM Subtype*					
	No SLD	*LH-SLD*	*RH-SLD*	*WM-SLD*	*PS-SLD*	*EX-SLD*
Spelling SLD	0 (0%)	11 (73%)	12 (86%)	26 (100%)	42 (88%)	24 (92%)
Group Total	56	15	14	26	44	26
Writing Fluency SLD	0 (0%)	8 (89%)	5 (46%)	9 (56%)	36 (77%)	20 (87%)
Group Total	38	9	11	16	47	23
Writing Samples SLD	0 (0%)	8 (53%)	9 (60%)	17 (63%)	36 (64%)	22 (67%)
Group Total	66	15	15	27	56	33

C-DM = concordance-discordance model; SLD = specific learning disabilities; LH = left-hemisphere deficit; RH = right-hemisphere deficit; WM = working-memory deficit; PS = processing-speed deficit; EX = WM and PS deficits; WJA = Woodcock Johnson Achievement.

TABLE 2
Descriptive Statistics for WISC-IV and WJ-III Writing Subtests for the No-SLD and WE SLD Subtypes

Factor/Subtest		*No-SLD*	*LH-SLD*	*RH-SLD*	*WM-SLD*	*PS-SLD*	*EX-SLD*	F^a
Wechsler Intelligence Scale for Children-Fourth Edition Indexes								
Verbal Comprehension	*M*	94.82	88.53	99.20	100.00	104.45	101.46	8.93
	SD	10.60	6.95	9.34	9.97	12.17	9.45	
Working Memory	*M*	95.04	93.47	90.20	81.47	97.50	84.83	17.26
	SD	10.95	9.27	9.94	9.39	8.25	7.67	
Perceptual Reasoning	*M*	95.38	105.60	82.53	106.03	106.18	103.77	15.15
	SD	12.21	11.92	5.84	11.50	12.70	10.69	
Processing Speed	*M*	93.99	95.87	85.00	98.10	79.85	82.97	21.16
	SD	11.05	11.74	7.69	11.47	10.22	8.87	
Woodcock Johnson-Third Edition Tests of Achievement Written Expression Subtests								
Spelling	*M*	93.48	86.13	82.93	82.62	86.55	80.73	5.33
	SD	12.44	11.87	13.03	8.68	14.42	11.59	
Writing Fluency	*M*	94.48	85.64	86.91	86.94	86.15	84.64	2.86
	SD	10.40	11.28	13.25	13.71	17.24	11.27	
Writing Samples	*M*	100.58	93.20	85.80	87.89	93.00	85.24	6.65
	SD	13.59	8.78	12.07	17.15	15.01	16.83	

WISC-IV = Wechsler Intelligence Scale for Children-Fourth Edition; WJ-III = Woodcock-Johnson Tests of Achievement-Third Edition; WE = written expression; SLD = specific learning disabilities; LH = left-hemisphere deficit; RH = right-hemisphere deficit; WM = working-memory deficit; PS = processing-speed deficit; EX = WM +PS deficit.

[a] $p < .01$, as expected given the concordance-discordance model definition.

RH-SLD, and EX-SLD subtypes had the lowest Spelling scores, but all subtypes had low-average performance. Low-average Writing Fluency scores were evident for all subtypes. The RH-SLD, WM-SLD, and EX-SLD subtypes had low-average mean Writing Samples scores.

For the neuropsychological profiles reported in Table 3, several subtype differences emerged. For the *auditory-language long-term memory* measures, the WRAML-2 Number-Letter (NL), Verbal Learning (VL), Verbal Learning Delayed Recall (VL-DR), Story Memory (SM), and Story Memory Delayed Recall (SM-DR) subtests were examined. Group differences were found on all measures except VL, which approached significance. Bonferroni post-hoc analyses for the NL subtest revealed the WM-SLD and EX-SLD

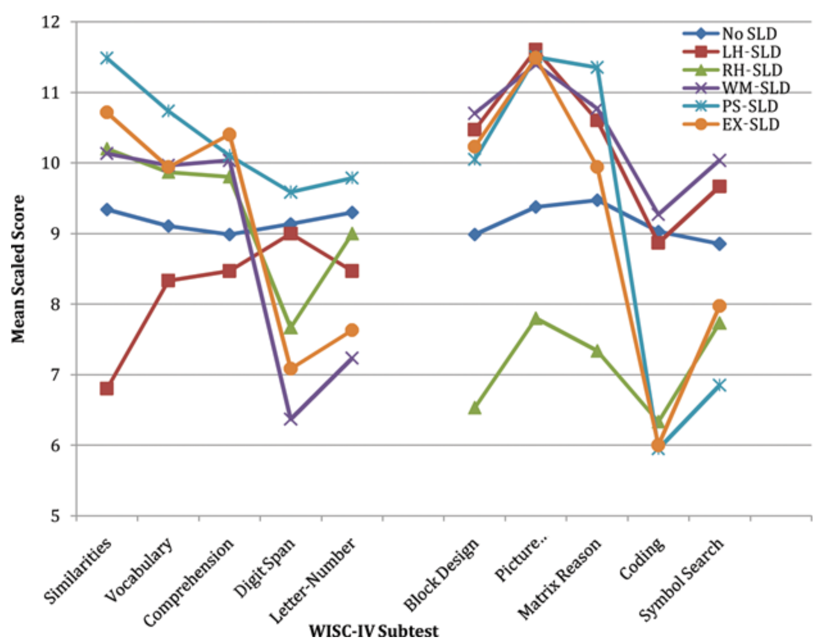

FIGURE 1 Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) subtest profiles of children with and without a written expression specific learning disability (SLD; F range = 3.43–20.37, p range .005 to <.001 as expected given concordance-discordance model definition). LH = left hemisphere; RH = right hemisphere; WM = working memory; PS = processing speed; EX = WM + PS deficit.

TABLE 3
No-SLD and Written Expression SLD Differences on Neuropsychological Tests

Factor/Subtest		*No-SLD*	*LH-SLD*	*RH-SLD*	*WM-SLD*	*PS-SLD*	*EX-SLD*	*F*[a]
Auditory-Language Long-Term Memory Processing Measures								
Number-Letter Seq.	*M*	9.32	8.81	10.22	8.26	10.28	8.09	3.71[b]
	SD	2.16	2.03	2.12	2.98	2.40	2.89	
Verbal Learning	*M*	9.78	7.80	10.11	8.84	9.28	9.22	1.98
	SD	2.25	1.78	1.97	2.57	2.47	2.30	
Verbal Learning-Delay	*M*	9.54	7.80	9.78	8.58	8.16	9.04	2.79[a]
	SD	2.00	1.97	2.24	2.50	2.01	2.55	
Story Memory	*M*	9.49	7.93	10.11	10.11	10.05	10.52	2.34[a]
	SD	2.49	2.28	3.06	2.45	2.59	2.47	
Storm Memory-Delay	*M*	9.68	7.20	11.00	9.68	9.77	9.96	5.07[b]
	SD	2.04	1.42	2.55	2.31	2.26	1.64	
Visual-Spatial-Holistic Processing Measures								
Finger Windows	*M*	7.61	8.27	6.67	7.00	7.63	7.72	0.75
	SD	2.38	2.32	2.35	2.21	2.49	2.91	
Design Memory	*M*	9.12	9.07	6.89	8.42	8.47	8.35	1.31
	SD	2.62	3.36	2.03	3.10	2.51	1.77	
VMI Visual	*M*	95.19	102.33	92.38	97.69	93.85	99.92	0.91
	SD	14.03	10.38	16.84	17.26	12.39	16.76	
TMT Visual Scan	*M*	9.53	11.75	6.67	9.67	6.67	10.83	2.87[a]
	SD	3.41	1.50	2.89	1.53	3.63	1.33	
Motor Sequencing-Constructional-Psychomotor Speed Measures								
VMI Motor		88.87	87.89	87.50	95.92	84.10	88.62	2.06
		11.98	11.27	13.64	10.10	13.09	5.69	
VMI Combined	*M*	92.65	90.64	89.90	92.63	94.57	92.13	0.53
	SD	8.87	11.97	8.09	11.97	10.79	9.84	
TMT Number	*M*	9.16	10.25	8.67	5.00	6.08	9.00	3.32[a]
	SD	3.24	2.06	3.06	3.90	2.57	3.10	
TMT Letter	*M*	8.37	9.00	8.33	7.33	7.31	7.67	0.21
	SD	3.61	2.16	4.62	5.03	4.48	2.16	
TMT Motor Speed	*M*	9.53	9.25	9.00	5.53	7.54	10.00	1.67
	SD	3.24	2.75	1.73	2.52	3.36	1.90	
Executive Working Memory-Interference-Retrieval Fluency								
Verbal Fluency-Letter	*M*	8.61	11.40	10.00	8.50	10.27	9.00	1.39
	SD	2.93	2.30	1.73	2.81	2.15	2.58	
Verbal Fluency-Categ.	*M*	10.11	10.80	11.67	9.50	9.18	8.30	1.05
	SD	3.71	1.64	2.08	2.88	2.64	1.70	
Design Fluency Switch	*M*	8.12	6.00	7.67	9.75	7.86	9.89	0.86
	SD	3.71	4.58	3.06	4.19	2.19	2.89	
Color-Word Interference	*M*	9.44	7.40	3.50	6.67	6.64	5.71	2.48[a]
	SD	3.16	4.16	2.12	1.53	2.66	3.73	
TMT Number-Letter	*M*	8.79	10.25	6.00	9.67	6.67	9.00	1.19
	SD	4.13	1.70	2.01	1.53	3.22	3.67	

Note. All scores are scale scores ($M = 10$, $SD = 3$), except VMI subtests ($M = 100$, $SD = 15$). SLD = specific learning disabilities; LH = left hemisphere; RH = right hemisphere; WM = working memory; PS = processing speed; EX = WM + PS deficit; Seq. = sequencing; VMI = Visual-Motor Integration; TMT = Trail-Making Test.

[a]$p < .05$. [b]$p < .01$.

subtypes had lower performance than the PS-SLD subtype. For VL-DR, the LH-SLD and PS-SLD subtypes performed worse than the no-SLD group. For SM, children with the LH-SLD subtype performed worse than those with the PS-SLD and EX-SLD subtypes. Lastly, for the SM-DR, the LH-SLD subtype scored lower than all other subtypes, including the no-SLD group. For *visual-spatial-holistic* measures, the WRAML-2 Finger Windows (FW) and Design Memory subtests, the VMI-6 Visual Perception subtest, and the D-KEFS Trail-Making Test Visual Scanning (TMT Vis) subtests were used. For these measures, differences emerged between SLD subtypes for the TMT Vis subtest only, with Bonferroni post-hoc analyses revealing the PS-SLD subtype scoring lower than the LH-SLD and EX-SLD subtypes. The FW subtest was low for all participant groups, with mean scores in the low-average range except for the LH-SLD group.

For the *motor sequencing-constructional-psychomotor speed* measures, the VMI-6 total (VMI) and VMI-6 Motor Coordination subtests, as well as the D-KEFS Trail-Making Test Number Sequencing (TMT NumS), Letter Sequencing, and Motor Speed measures were administered. Differences were noted among SLD subtypes for the TMT NumS subtest, with post-hoc analyses revealing that the PS-SLD group performed worse than the LH-SLD subtype and no-SLD group. Finally, the *working-memory-interference control-retrieval fluency* executive measures consisted of the D-KEFS Verbal Fluency Letter Fluency and Category Fluency measures, the Design Fluency Switching, the Color-Word Interference Inhibition (CW), and the Trail-Making Test Number-Letter Switching subtests. Subtype differences emerged for the CW subtest only, with post-hoc analyses revealing the EX-SLD and RH-SLD groups performed worse than the no-SLD group.

DISCUSSION

There are many reasons why children struggle with learning, only one of which is SLD. To understand WE differences among children with SLD, SLD subtypes, and low achievement, a PSW approach may be useful, because neither RTI nor AAD identify the processing deficits causing the WE problem (Fiorello et al., 2012; Hale, Alfonso et al., 2010; Wright et al., 2013). The present C-DM study provides an initial attempt to examine WE SLD subtype performance on neuropsychological measures of auditory-language long-term memory, visual-spatial-holistic processes, motor sequencing-constructional-psychomotor speed, and executive working-memory-interference control-retrieval fluency processes, which have been identified as potential causes of WE SLD (Hooper et al., 2011).

In the present study, spelling deficits across cognitive-processing weaknesses confirm that multiple processes, including phonological (auditory), orthographic (visual), and morphemic (lexical-semantic knowledge; Berninger, Abbott, Nagy, & Carlisle, 2010), are needed for spelling competency. Deficits could result from linguistic deficits (LH-SLD), visual memory for morphemes (RH-SLD), auditory-sequential deficits (WM-SLD), visual-orthographic problems (PS-SLD), or visual-sequential processing (EX-SLD; e.g., Bahr, Silliman, Berninger, & Dow, 2012; Berninger et al., 2010; Gebauer et al., 2012; Hooper et al., 2002; Zins & Hooper, 2012). Alternatively, spelling difficulties could be the result of poor graphemic or allographic motor representations in Exner's area (Purcell, Napoliello, & Eden, 2011). However, few visual-motor-constructional differences were found in the present study. This could suggest that deficits in visual-somatosensory-motor coordination for handwriting (e.g., Klein, Guiltner, Sollereder, & Cui, 2011) may only be relevant for a select subset of children not easily identified using the psychometric C-DM approach used in this study. However, visual-spatial-motor processes for visuoconstructional VMI skills may not be as relevant as sequential-processing weaknesses in recognizing WE SLD subtype spelling deficits (Richards et al., 2009), which would be consistent with the sequential motor deficits found in this (e.g., TMT differences, low FW performance across subtypes).

For Writing Fluency, difficulty in lexical-semantic knowledge (LH-SLD), graphomotor speed when writing (PS-SLD), and/or speeded sequential processing and error monitoring (EX-SLD) may potentially contribute to poor performance. Clearly, lexical-semantic and expressive language processes are important for WE and the likely source of the LH-SLD subtype deficits (Hooper et al., 2011). However, neuropsychological profile analysis also suggests that sequential-processing deficits may be a potential source of LH-SLD WE deficits, showing this strong interrelationship between executive, motoric, sequential, and linguistic processes (Berninger et al., 2008; Koziol et al., 2013). The WM-SLD and EX-SLD subtypes struggled with the VL-DR subtest, suggesting possible working-memory problems in both subtypes, which could account for their poor writing fluency (Gathercole & Baddeley, 2014; McCutchen, 2011). The WM-SLD subtype may have difficulty translating the stimulus words required into their sentences or monitoring the sentence components as they attempt to construct grammatically sound sentences. In contrast, the writing fluency problems for the EX-SLD subtype may reflect poor executive retrieval or decision making for language formulation during quick, efficient, grammatically correct sentence writing. This hypothesis would be consistent with this subtype's difficulty with interference or inhibition, as has been found in studies of attention-deficit hyperactivity disorder (ADHD) and executive and WE deficits (Bledsoe, Semrud-Clikeman, & Pliszka, 2009). However, the PS-SLD subtype also had difficulty with writing fluency and verbal learning retrieval and had low scores on all TMT tasks, consistent with prior research showing the relevance of white-matter integrity, fluent performance, and processing speed (e.g., Flöel, de Vries, Scholz, Breitenstein, & Johansen-Berg, 2009; Gebauer et al., 2012; Rindermann, Michou, & Thompson, 2011) in WE competence. It may be that without sufficient processing speed, working memory gets taxed during the writing process, which in turn limits ideational fluency and mental flexibility necessary for good WE output (e.g., Rose, Feldman, & Jankowski, 2011).

No distinct relationships were found among C-DM SLD subtypes for the Writing Samples subtest. Given the importance of multiple neuropsychological processes in WE competence, executive functions likely play a critical role (Altemeier, Jones, Abbott, & Berninger, 2006; Graham, Harris, & Olinghouse, 2007; Hooper et al., 2011). In fact, WE competence requires the ability to plan, organize, strategize, implement, monitor, evaluate, and revise the writing sample—the same dorsolateral processes tapped by many executive function measures. The EX-SLD subtype had lower mean Writing Samples scores than any other subtype, and their poor performance on the D-KEFS CW subtest might suggest that inhibition, response selection/interference, and/or performance monitoring may have contributed to their WE deficits (Berninger et al., 2008; Hooper et al., 2011). In addition, Writing Samples subtest difficulties were also evident for the other executive-related subtypes (WM-SLD and PS-SLD), so executive-based subtypes displayed profiles similar to children with ADHD who have executive and WE deficits (Tannock, 2012; Yoshimasu et al., 2012). However, the other executive measures did not differentiate subtypes, so perhaps they were not sensitive to WE executive requirements. Alternatively, these findings may reflect the structured nature of the WJ-III Writing Samples task, which asks the child to write single sentences using words and pictures provided, rather than writing an unstructured essay on a topic, thus limiting the need for executive functions typically required in WE (e.g., Hooper et al., 2011).

Children in the RH-SLD group deserve special attention given that some WE research shows the relevance of visual-spatial processes (e.g., Carlson, Rowe, & Curby, 2013), while others show little relationship with WE in typical children (Floyd, McGrew, & Evans, 2008). This RH-SLD subtype had the lowest mean score on all visual-spatial measures in this study, suggesting their writing difficulties are not specifically related to linguistic competency, which was a relative strength. Performance on the WRAML-2 FW task was poor across all C-DM SLD subtypes, thereby highlighting the need to consider spatial sequential-processing deficits in WE or disability in general, but not necessarily any WE SLD in particular. Some might suggest that the WE SLD deficits in this group may be related to visualization of the topic for subsequent WE (Olive & Passerault, 2012), but when one considers the importance of right-hemisphere processes in fluid reasoning, complex language relationships, and ideational flexibility (e.g., Bryan & Hale, 2001; Floyd et al., 2008; Kaufman, Kaufman, Liu, & Johnson, 2009; Takeuchi et al., 2010), this could explain their WE problems. Visual search skills were poorer for both the RH-SLD and PS-SLD groups, suggesting that sustained attention may be important to consider during WE for these subtypes, especially in light of research linking right-hemisphere function to ADHD and vigilance (Hale et al., 2013) and ADHD processing deficits that predict WE competency (e.g., DeBono et al., 2012).

In addition to cognitive and academic profiles, neuropsychological test results provide critical information for understanding a child's unique learning difficulties across academic domains, or even within the same domain. When combined with a CHT neuropsychological approach, C-DM provides a practical and comprehensive tool to illuminate the relationship between PSW and academic achievement, thus staying true to statutory definitions that emphasize processing deficits as a hallmark characteristic of SLD (Dehn, 2014; Hale, Alfonso et al., 2010). For example, C-DM has been advocated for use in neuropsychological practice (Miller, Getz, & Leffard, 2006), has been adopted by standardized achievement tests (e.g., Wechsler, 2009), and is supported by both diagnostic and treatment validity studies,[1,2] making it a potentially practical SLD clinical and research tool. In addition, the PSW method also helps differentiate SLD from low academic achievement, SLD subtypes, and other disorders.

This study provides preliminary evidence for the relevance of identifying and understanding neuropsychological processes to best support the individual needs of children with SLD. However, it is important to note that although processes help us understand WE SLD and other disorders, their definition, operationalization, and assessment are an ongoing challenge for the field of neuropsychology. Psychology is replete with poorly operationalized terminology, and yet, psychological constructs may be considered definitive in many social, legal, and practice contexts. The frequently used generic constructs of "cognition" and "psychological processes" are umbrella terms meant to reflect global concepts, but in reality, they are poorly defined. Perhaps a psychological process is a mental action defined by central nervous system neuronal activity (e.g., LeDoux, 2002). However, this neurocellular and neurochemical activity occurs with and without "thought" or "volition" or "action," and some processes require integration of brain structures and systems not under conscious control (e.g., Cromwell & Panksepp, 2011; Koziol & Budding, 2009). Providing a list of brain-based psychological processes (e.g., phonological awareness, visual discrimination, sequential memory, executive planning, sustained attention) and linking them to brain structures/systems may facilitate interdisciplinary recognition and foster ontological convergence (e.g., Hastings et al., 2014). However, the measures used to evaluate these processes are never specific to single brain structures or even systems, nor are they comparable across test batteries. This explains why similar test scores can be found for children with very different brain-based determinants. As a result, the C-DM approach presented here is inherently limited by this ontological issue, and ultimately, practitioners can only understand the child's processing weakness as it relates to an achievement deficit within the context of the measures used and outcomes observed. Otherwise, one runs the risk of assuming that a ‘‘processing weakness’’ is an automatic indicator of an SLD, which is the same illusion practitioners entertained when discrepancy was equated with SLD.

Limitations and Future Directions

Study results may have been attenuated in this clinical sample because participants could not have intellectual disability but had to have below-average WE performance, which restricted the range and limited subtype sample size, thereby decreasing power. Another significant limitation was the use of a strictly psychometric C-DM approach; thus, processing weaknesses could not be verified as the cause of WE deficits. Additionally, this study was limited by the specificity of study measures; because neuropsychological ‘‘processes’’ defined by psychometric measures cannot adequately evaluate the numerous brain structures, circuits, or systems required for WE competency and because these measures are factorially complex and not orthogonal, they may not reflect the same underlying determinants for different children or different WE task requirements. For instance, it is possible that a poor auditory working-memory score may reflect an underlying phonological sequencing deficit (e.g., Asberg, Kopp, & Gillberg, 2014) on a spelling test, but a low score could reflect a working-memory problem on a writing fluency task. This may also be the case with the PSI Coding subtest, often thought of as a measure of processing speed and graphomotor skills. However, research has confirmed that it also measures the associative learning processes of the inferior parietal lobe (see Hale et al., 2012), the same region thought to be critically important in phoneme–grapheme correspondence for spelling competency (Berninger et al., 2010). Because brain structures, circuits, and systems cannot be uniformly understood using single measures, a neuropsychological—not a psychometric—interpretive approach is needed to understand the relationship between objective measures and WE competence and SLD. As Luria (1980) noted, WE deficits can result from disruption of, or damage to, diverse cortical and subcortical areas, with only the ‘‘peculiarities’’ of WE output highlighting where the problem is occurring within the context of the complex functional system that governs WE. Clearly, there is a need to link brain structure and function of neuropsychological measures and their relationship with academic achievement using structural and functional imaging techniques.

Future research should also be conducted to verify the relationship between the processing deficit and WE SLD using CHT and the eight-step C-DM method described by Hale, Wycoff, et al. (2010). It would also be useful to explore other measures that require a spontaneous writing sample, such as the Weschler Individual Achievement Test (WIAT-III) or Test of Written Language (TOWL-3). The WJ-III Writing Samples subtest may not tap executive processes necessary for a child to compose a small essay, which would reveal clearer information on how a child actually generates ideas and translates them in the WE product (e.g., Altemeier et al., 2006). This also touches on the need for more unstructured WE tasks when evaluating children with WE SLD, as idea formulation, theme development, ideational flexibility, and organization are not tapped on the WJ-III Writing Samples subtest. If the task was less explicit or more creative, children would likely be required to recruit more right-hemisphere linguistic functions to produce novel, divergent, or complex prose (e.g., Bryan & Hale, 2001; Koziol et al., 2013; Takeuchi et al., 2010) or use implicit language for creative writing or poetry (Faust & Mashal, 2007). Even with this limitation, it is important to note the relevance of processing speed in this study, with white-matter integrity/connectivity, right-hemisphere functions, and fluent performance (e.g., Bryan & Hale, 2001; DeBono et al., 2012; Turken et al., 2008) linked to WE competency, which would be reflected in the RH-SLD/PS-SLD WE deficits found in the present study. Finally, it is important to note that environmental factors such as prior experience and education continuously interact with individual child characteristics to fundamentally alter brain structure and function during neurodevelopment (Koziol et al., 2013). Therefore, future research should examine how environmental influences impact neurodevelopmental sequelae associated with SLD subtype patterns.

WE is likely the most difficult academic subject one must learn in school (Hale & Fiorello, 2004), yet it receives the least amount of empirical attention (e.g., Berninger et al., 2008). WE difficulties and disorders occur at alarmingly high rates in children (Zins & Hooper, 2012), and for children with SLD, these deficits persist into adulthood even when other literacy skills have improved (Harrison, 2009). WE requires multiple brain functions and systems to work in an integrated fashion, and a deficit in one or more of these processes may result in WE SLD (Berninger & Dunn, 2012; Hooper et al., 2011; Lorch, 2013). Clearly, significant empirical work is necessary to understand the PSW associated with WE spelling, writing fluency, and WE deficits, so affected children can receive the differentiated instruction and targeted interventions necessary to ameliorate their WE deficits.

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