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Diagnostic implications of the double deficit model for young adolescents with dyslexia

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Considerable support exists for both the phonological core deficit and the naming speed deficit models of dyslexia. The double deficit model proposed that many students with dyslexia might also be impaired in both underlying processes. Employing either performance thresholds (i.e., scores below the 16th or 25th percentile) or *k*-means clustering as classification methods, the current study investigated whether 154 young adolescents with dyslexia could be categorized into subtypes according to the presence or absence of phonological deficits alone, naming speed deficits alone, or a combination of the two and whether group composition changed depending on classification method. Results support the existence of both single and double deficit groups and confirm that those with both deficits are the most severely impaired across multiple measures. Contrary to previous research, most adolescents were classified as either naming speed only (about a third of the group) or double deficit when defining impairment using performance thresholds to classify groups. This may suggest that although early phonological deficits are amenable to remediation, identification of language symbols fails to become automatized in most individuals with dyslexia and may require more targeted intervention. Classification differences reported in the literature may depend on age and methods employed for classification.

KEYWORDS
adolescents, double deficit, dyslexia, naming speed

1 | INTRODUCTION

Different models of dyslexia logically lead to different practices in terms of assessment, identification of problems, and remediation. At present, there is considerable support for both the phonological core deficit model and the rapid naming speed deficit (RND) model of dyslexia. The phonological core deficit model presumes that, in general, dyslexia results from deficits in phonological processing skills, such as phonological awareness and phonological retrieval. However, some researchers (De Luca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; De Luca, Burani, Paizi, Spinelli, & Zoccolotti, 2010) have identified children with dyslexia who have intact phonological awareness. Research has identified problems with visual naming speed in those with dyslexia, demonstrated primarily on rapid automatized naming tasks (Denckla & Cutting, 1999). Rapid automatized naming reliably distinguishes children with dyslexia from normally developing readers, "garden-variety" poor readers, and readers with other specific learning disorders (for an overview, see Wolf, Bowers, & Biddle, 2000). Hence, support also exists for the notion that some disabled readers may have difficulty mainly with rapid naming.

The double deficit (DD) model is based on the premise that word reading difficulties associated with dyslexia may be caused by a combination of these two types of deficits (Wolf & Bowers, 1999). Within the DD model, naming speed is conceptualized as multivariate in its underlying causal mechanisms and linked to reading in that it involves retrieval of verbal labels for visual stimuli (Denckla & Cutting, 1999). Proponents of the DD model would seek to discriminate between phonological awareness deficits (PADs) and naming speed deficits and to centre intervention efforts on both phonological and fluency skills.

Support for the DD model comes first from the finding that, though correlated, naming speed and phonological awareness often account for unique variance in reading measures (Lesaux & Siegel, 2003; Manis, Doi, & Bhadha, 2000; Manis, Seidenberg, & Doi, 1999; Wolf et al., 2002) and development of reading skills (Vaessen & Blomert, 2010). Additionally, there is evidence that the relationship between phonological awareness and rapid naming varies with the type of reading tasks used (Compton, DeFries, & Olson, 2001) or different degrees of impairment (Manis, Seidenberg, Stallings, et al., 1999). Phonological awareness has been shown to be a primary factor underlying early reading achievement (Ehri, Nunes, Willows, Valeska-Schuster, Yaghoub-Zadeh, & Shanahan, 2001). Phonological awareness is closely associated with phonetic decoding, and highly predictive of reading skill in the early elementary grades, before children have established large sight word vocabularies. Conversely, although rapid naming is associated with reading skills (Kirby, Georgiou, Martinussen, & Parrila, 2010), few studies have examined the developmental course of rapid naming itself, even in normally developing readers (Araújo, Reis, Petersson, & Faísca, 2015; Georgiou et al., 2014). We do, however, know that naming speed is often associated with measures of reading speed (Compton et al., 2001; Katzir, Kim, Wolf, Morris, & Lovett, 2008). Further, rapid naming appears to be a better predictor of reading outcomes in older children (Parrila, Kirby, & McQuarrie, 2004). Both Catterson (2006) and Kirby, Parrila, and Pfeiffer (2003) found this developmental pattern, with phonological skills predicting success in early reading and naming speed better predicting reading skills in later elementary grades. Van den Bos, Zijlstra, and Lutje Spelberg (2002) also found a developmentally increasing relationship between alphanumeric naming speed and reading after about age 12 that continues into adulthood. Multiple studies have successfully classified disabled readers according to deficits in phonological awareness, naming speed, or both (Manis et al., 2000; Sunseth & Bowers, 2002; Wolf et al., 2002). The DD group often encompasses the largest proportion of children with dyslexia, but sizeable minorities fall into the single deficit groups. Several of these studies have found that readers who demonstrate both deficits also demonstrate the greatest impairment in reading skills (Papadopoulos, Georgiou, & Kendeou, 2009; Waber, Forbes, Wolff, & Weiler, 2004). Findings regarding those with single deficits are less consistent. Lovett, Steinbach, and Frijters (2000) and Compton et al. (2001) found that children with phonological deficits performed more poorly on measures of phonetic decoding but found no differences between groups on real word reading or spelling. Lovett et al. also found that children with naming speed deficits had higher verbal reasoning ability than those with phonological deficits. Katzir et al. (2008) found that children with naming speed or phonological deficits did not differ on single word reading accuracy, phonetic decoding accuracy, or comprehension, but the group with phonological deficits outperformed the naming speed group on reading speed measures at the word and connected text levels.

An alternate interpretation of the phonological and naming speed findings is that they are simply two manifestations of a unitary underlying phonological processing skill. According to this view, the ability to form phonological representations affects both one's ability to identify and manipulate the sounds of speech (phonological awareness) and the ability to rapidly retrieve phonological codes from long-term memory or to quickly recode in lexical access (naming speed; Wagner & Torgesen, 1987; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993). Proponents of this view cite strong correlations between phonological awareness and naming speed (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Wagner et al., 1993) and their similar relationships to word reading (Hammill, Mather, Allen, & Roberts, 2002). Furthermore, some have found that virtually all individuals with dyslexia demonstrate PADs, whereas isolated RNDs are highly uncommon (Badian, 1997; Vukovic & Siegel, 2006). In fact, Vukovic and Siegel's (2006) systematic review of the existing DD literature concludes that "there appear to be few or no individuals with dyslexia who have a naming speed deficit but intact phonological skills" (p. 35).

As Wolf and Bowers (1999) state, the extent to which phonological awareness and naming speed are indeed independent has "profound implications for how researchers diagnose, predict, and treat children with developmental dyslexia" (p. 415). If all deficits are fundamentally phonological in nature, then no prognostic value is gained from identifying distinct deficits in phonological awareness or naming speed, and remediation need not be tailored to one specific deficit or the other. Additionally, researchers need not classify individuals into distinct subtypes (or, at least, not into these distinct subtypes) in order to increase the homogeneity of research samples. Alternatively, if the DD model more accurately describes the underlying causes of dyslexia, then one might expect that single deficits can not only be identified but can be reliably associated with different reading profiles or associated features. As such, remediation that targets specific deficits will be more productive than that that assumes all word reading deficits to be rooted in phonological deficiencies.

Most of the existing studies of the DD model have focused exclusively on reading skills. However, if phonological awareness and naming speed reflect distinct underlying cognitive processes, then one might expect to be able to identify logically related associated features outside of the reading domain. For instance, to the extent that phonological awareness is rooted in the ability to form highly specified phonological representations, one would expect individuals with PAD to demonstrate deficits in other skills reliant on the establishment of phonological representations. Individuals whose deficit falls squarely in the phonological domain might have difficulty learning new or foreign vocabulary or retaining speech-based information in short-term or working memory (Gathercole & Pickering, 2000).

In contrast, individuals who display intact phonological awareness but RND tend to perform more slowly on a wide variety of speeded motor, visual, lexical, grammatical, and phonological tasks (Catts, Gillespie, Leonard, Kail, & Miller, 2002; Kirby et al., 2010; Nicolson & Fawcett, 1999). Academically, there is some evidence that naming speed is also related to spelling ability above and beyond the relationship between phonological skills and spelling (Savage, Pillay, & Melidona, 2008). Kirby et al. (2010) provide an excellent review of the research regarding the possible contributions of rapid automatized naming to the development of reading skills in younger children.

When Vukovic and Siegel (2006) conducted their systematic review of the literature, they concluded that few to no individuals with dyslexia had isolated rapid naming deficits; however, the 28 studies they reviewed (only 10 of which examined the DD model directly) dealt with younger children as opposed to adolescents. Further, they noted the lack of consistency among existing studies regarding criteria used to classify children as reading impaired, ranging from use of an undefined discrepancy formula, reading below grade level, all the way to word reading scores below the 16th percentile. Few of the studies reviewed measured all aspects of reading (e.g., accuracy, fluency, and comprehension), and the sample sizes of most previous studies were too small to test the hypotheses of the DD model adequately. It is therefore relevant and important to determine whether RND-only adolescents with dyslexia can be identified and to also examine the impact that different methods of classification have on the number of individuals found to have each type of profile.

It is also possible that different interventions provided earlier in a child's life may affect the proportion of adolescents who show one or both types of deficits. For instance, most young children who demonstrate early reading difficulties are provided with some type of phonological training programme, first given by their classroom teacher and then by a trained specialist if the initial intervention is not successful (Reynolds & Shaywitz, 2009). Such early intervention is associated with improved phonological awareness (Ehri et al., 2001; Lovett & Steinbach, 1997; Scanlon & Vellutino, 1997; Solis et al., 2012). However, these interventions typically fail to address rapid naming deficits (Vander Stappen & Reybroeck, 2018). Earlier interventions may also have different success rates. For instance, developmental data reviewed in the technical manual, the Comprehensive Test of Phonological Processing (CTOPP: Wagner, Torgesen, & Rashotte, 1999), support the notion that phonological skills are highly responsive to remedial intervention with struggling young readers (ages 5–6), whereas rapid symbolic naming skills show no notable improvement after targeted naming speed intervention in same-aged children with reading difficulties.

The window for making meaningful changes in these two skills may also be rather limited. For example, developmental changes in normally achieving children suggest that, on average, both speed of lexical retrieval and phonological awareness skills increase rapidly between ages 5 to 10 and plateau after about age 14 (McGrew, LaForte, & Schrank, 2014). Meyer, Wood, Hart, and Felton (1998) studied the developmental progression in naming speed abilities of children from Grades 1 to 8 and found that naming speed abilities plateau by about eighth grade. Similarly, Van den Bos et al. (2002) studied the lifespan development of rapid naming skills and found that speed of both letter and number naming plateau at around age 16 in normally developing readers. These authors also found an increasing correlation between reading skill and alphanumeric naming speed over time; naming speed is weakly associated with reading before age 10 but becomes increasingly important after that age. One might therefore hypothesize that the manifestation of deficits in struggling readers may change over time such that adolescents who were exposed to remedial intervention earlier in their school careers may have improved their phonological awareness abilities while their rapid naming skills may not have enjoyed any notable improvement. If true, then one would expect there to be fewer adolescents with DDs or isolated PADs and relatively more struggling readers who continue to have deficits in rapid naming alone.

An issue that further complicates past studies is that they included students with co-morbid attention deficit hyperactivity disorder (ADHD) in the samples. Given that ADHD is often co-morbid with dyslexia (Willcutt, Pennington, Olson, & DeFries, 2007) and that individuals with ADHD have been found to have deficits in naming speed (Rucklidge & Tannock, 2002; Ryan et al., 2017), previous studies may have inadvertently identified naming deficits associated with ADHD as opposed to dyslexia.

The present study was thus undertaken to address the deficiencies identified in previous studies of the DD model in a sample of young adolescents with dyslexia in order to explore several questions. First, after removing students with diagnoses of ADHD, how prevalent are the PAD, RND, and DD subgroups in adolescents with a long-standing dyslexia? Additionally, do students with co-morbid ADHD demonstrate deficits primarily with naming speed, thus perhaps confounding the results of prior studies? Next, given the variability noted by Vukovic and Siegel (2006) in methods used to classify children as dyslexic, what impact does method of group classification have on group composition or size? Third, are phonological awareness and naming speed deficits reliably associated with different cognitive or academic skill profiles? Finally, do those adolescents with a DD profile exhibit more severe academic deficits than those with only a single deficit? In addition, this study aimed to ensure clinical relevance of the findings by using standardized, commercially available tests that are in common use in psychoeducational assessments. In this manner, the present study hoped to evaluate the clinical implications of the DD model by describing test score profiles that would be expected for individuals demonstrating deficits in different underlying skills.

2 | METHOD

2.1 | Participants

Participants were drawn from a total of 268 Grades 7 and 8 students seen for updated psychoeducational assessments in a programme designed to assist students with dyslexia in making the transition from elementary to secondary school. All students had been assessed and identified as "learning disabled" under the Ontario Ministry of Education criteria for exceptionality (Ontario Ministry of Education, 2017) sometime prior to the sixth grade.

One hundred and fourteen students were removed from the analyses. These included those with co-morbid ADHD (n = 48), students whose impairment was not primarily in reading (i.e., math problems, dysgraphia, and nonverbal learning disability, n = 32), and students who did not fully complete the psychoeducational assessment (n = 33). One student with a Full Scale Intelligence Quotient (FSIQ) less than 70 was removed from the analysis. Hence, of the 268 students assessed, 154 were selected in the primary analysis. The resulting sample was 64.7% male. Ages ranged from 11 years 8 months to 14 years 10 months with an average age of 12 years 4 months. Adolescents in the current sample were of average intelligence (mean FSIQ = 94.64, SD = 11.2). The project was carried out in a Canadian city with individuals primarily of middle socio-economic status according to the Hollingshead index.

2.2 | Procedure

All students were seen for psychoeducational assessments supervised by a licensed psychological practitioner. Each assessment consisted of a core battery of intellectual, cognitive, and academic tests plus any additional testing required to evaluate the difficulties of specific students. The assessment sought not only to examine the reasons for experienced reading difficulties but also to evaluate cognitive strengths and determine if other co-morbid conditions might be affecting learning. Age-based norms for each measure were used to interpret obtained raw scores. However, some students were not administered the full test battery due to time constraints (where tests not relevant to their specific complaints were not administered if time was limited) or (rarely) the need to maintain rapport by avoiding tasks that were clearly too difficult. These missing data were therefore unbiased but resulted in variations in sample sizes across some tests in the analyses.

2.3 | Measures

All measures are drawn from individually administered, standardized tests that are commercially available and commonly used in psychoeducational assessments. Unless otherwise stated, scores used in the analyses are standard scores with a mean of 100 and standard deviation of 15 based on the American standardization samples for each test.

2.3.1 | Deficit group indicators

Phonological Awareness

Phonological Awareness was measured with the Elision and Blending tasks from the CTOPP (Wagner et al., 1999). The Elision task requires that individuals isolate and remove individual sounds from words in order to articulate new words (e.g., say "sting" without the /t/ sound). The Blending task requires the individual to blend discretely presented sounds to create whole words. The score is the number of items correctly completed. Scaled scores from the two tasks are combined to create a Phonological Awareness composite score.

Naming Speed

Naming Speed was measured with the Digit Naming Speed and Letter Naming Speed tasks from the CTOPP. In these tasks, a series of digits or letters is presented (nine digits per row over four rows), and the individual is asked to read them aloud as quickly as possible. Time to complete each page is converted to scaled scores for each task, and scaled scores from the two tasks are combined to form a Naming Speed composite score.

2.3.2 | Cognitive skill measures

Reasoning

Reasoning was assessed with the Verbal Comprehension and Perceptual Reasoning indices of the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV: Wechsler, 2003). Verbal Comprehension is a measure of verbal reasoning and requires that the individual defines words, makes associations between ideas, and explains common social conventions or real-life problems. The Perceptual Reasoning index measures non-verbal/perceptual reasoning and requires analysis and synthesis of geometric designs, interpretation of patterns, and making associations between pictured ideas.

Memory

Tasks were administered to measure several aspects of memory. Auditory working memory was assessed with the Working Memory index of the WISC-IV, which includes digit repetition (forward and backward) as well as number–letter sequencing tasks. These tasks require the mental reorganization of auditory information as it is held in short-term store. The Verbal Memory composite from the Wide Range Assessment of Memory and Learning-Second Edition (WRAML-II; Sheslow & Adams, 2003) was used to represent more contextualized verbal memory. The two tasks that make up this composite require memory for the details of stories read aloud and memory for a word list presented repeatedly. Finally, visual memory was assessed with the Visual Memory composite from the WRAML-II, which requires individuals to reproduce the details of geometric designs that were shown to them for 5 s and to remember and note the details of pictured scenes shown for 10 s.

Cognitive Perceptual Speed

The Processing Speed Index from the WISC-IV was used as a measure of cognitive perceptual speed. The two timed tasks that comprise this score require copying abstract symbols according to a response key and scanning a response set for the presence of one of two target symbols. Raw scores represent the total number of items completed in a 2-min time period. These are converted to scaled scores, which are then combined to form the Processing Speed Index. Additionally, the Processing Speed score was also computed from two subtests from the Woodcock–Johnson III (Woodcock, McGrew, & Mather, 2001).

2.3.3 | Academic skills

Word-level skills

a Phonetic decoding ability: This was assessed with the reading of regularly spelled pseudowords. Phonetic decoding accuracy was measured with the Pseudoword Decoding task from the Wechsler Individual Achievement Test-Second Edition (WIAT-II; Wechsler, 2001), an untimed task that requires the student to accurately read out nonsense words (e.g., “finlap” and “jelp”). Phonetic decoding speed was assessed with the Pseudoword Decoding Efficiency task from the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999), which allows a 45-s time limit in which the individual must sound out as many nonsense words as possible (e.g., snark and yerp).

b Real word decoding ability: Real word reading was assessed in terms of both accuracy and speed. The Word Identification task from the WIAT-II, which requires untimed reading of progressively more complex real words, was used as a measure of word reading accuracy, whereas the Sight Word Efficiency task from the TOWRE was used to measure word identification speed. Finally, the Spelling task from the WIAT-II was used.

Text-level skills

Text reading speed was assessed using the time taken to read the passages that comprise the WIAT-II Reading Comprehension task. Although students are given the option to read aloud or silently, all students chose to read silently. The score for this task is the time taken to read the set of Grade 7 passages. The WIAT-II Reading Comprehension standard score was used to represent the ability to understand text.

Mathematics skills

The ability to carry out written arithmetic operations and to solve mathematics problems read aloud was assessed with the Numerical Operations and Math Reasoning subtests of the WIAT-II.

3 | RESULTS

Data analysis began by determining if the clinical data could be subtyped according to deficits in phonological awareness, naming speed, or both. Following the standards set out in the *Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition* (American Psychiatric Association, 2013), a cut-off for identification of impairment in functioning of below the 16th percentile (the lower boundary for one standard deviation below the mean) was employed. Students whose Phonological Awareness Composite score on the CTOPP fell below the 16th percentile but whose Naming Speed Composite score on the CTOPP was at or above the 16th percentile were classified as having a PAD. Students whose Naming Speed scores fell below the 16th percentile but whose Phonological Awareness scores were at or better than the 16th percentile were included in the RND group. Students who performed below the 16th percentile on both Naming Speed and Phonological Awareness were classified as DD. Those who did not fit into any category were classified as having no deficit in either skill (ND). The number of students classified into each group is shown in Table 1.

Given that some researchers classify students as dyslexia if their performance falls below the 25th percentile on tests of academic achievement (Shaywitz & Shaywitz, 2005; Siegel, 2006), this study next investigated changed group composition if the 25th percentile were employed as the threshold by which students would be identified as impaired by the CTOPP classification method. Finally, *k*-means clustering on CTOPP Phonological Awareness and Rapid Naming scores was used as a means of determining group membership. *k*-means clustering is an iterative partitioning technique used to group individual cases most similar to each other. Four clusters were specified prior to conducting the analysis. Using Euclidean-squared distance, the final clusters produced were closely aligned with our original participant classification on ND and DD but had altered PAD and RND. Table 1 shows group membership for these two additional classification methods.

TABLE 1 Student group assignments using various classification methods

	Cut-off		
Group	**16th percentile**	**25th percentile**	***k*-means**
No deficit	42	23	36
PA deficit	23	24	49
RN deficit	48	47	30
Double deficit	41	60	39

Note. $N = 154$.

Abbreviations: PA, phonological awareness; RN, rapid naming speed.

Of interest, when percentile cut scores were employed, the majority of adolescents were classified as having either RNDs or a DD; however, when using the 16th percentile as an indicator of impairment, a sizeable number of students (27%) were found to have neither deficit. As may be seen, when employing the *k*-means method of classification, the DD and ND groups remained relatively stable, but significantly more students were diagnosed as PAD and fewer diagnosed as RND; 24% were still classified as having no deficit.

Although removed from the main analyses, if those students with co-morbid ADHD had been included in the analysis, they would have been classified primarily as having either RND or DD. Indeed, using either the 16th or 25th percentiles as impairment classification metrics, the majority of adolescents with co-morbid ADHD (44% and 42%, respectively) were classified as RND, with the remainder falling largely in the DD group (25% and 27%, respectively).

3.1 | Cognitive and academic profile differences

We compared the cognitive and academic profiles of PAD and RND students to investigate whether adolescents classified in this manner demonstrated significantly different learning and processing profiles. Interestingly, apart from CTOPP scores (used for initial classification), RND students classified using either the 16th percentile or *k*-means scored significantly lower ($p < 0.05$) on Coding, Reading Fluency, and the TOWRE Total score but showed no difference in Coding if classified using the 25th percentile. No other significant differences were found between groups.

The next question examined was whether the four groups identified using the 16th percentile (PAD, RND, DD, and ND) were different from each other in cognitive or academic domains (see Table 2). Past research had suggested that the DD group would, on average, perform worse than PAD or RND across measures related to reading or language processing skills. Consistent with method of group classification, an analysis of the mean score of the CTOPP composite scores using a one-way ANOVA showed significant between-groups differences in Phonological Awareness, $F(3, 150) = 81.352$, $p < .001$, and Rapid Naming, $F(3, 150) = 83.882$, $p < .001$. Differences on WISC-IV, WIAT-II, TOWRE, Woodcock–Johnson III, and WRAML subtests were also explored using one-way ANOVA. All pairwise comparisons were adjusted for using Bonferroni correction (see Table 2 for a list of the full test battery). As may be seen, the DD group scored significantly lower than the ND group on Coding, Processing Speed, and FSIQ variables from the WISC. Academically, they were significantly lower than the ND group on Word Reading, Numerical Operations, TOWRE subtests, Reading Fluency, and Oral Reading. The DD group also performed significantly lower than the RND group on Working Memory, untimed Word Reading on the WIAT-II, and all TOWRE subtests.

Finally, this study also investigated the number of adolescents in each of the four groups (defined as below the 16th percentile on one or more CTOPP composite measures) who performed below the 16th percentile on other achievement measures administered as part of this comprehensive assessment (see Table 3). With the exception of spelling, substantially more of the adolescents classified as DD demonstrate impairment as measured by performance on other achievement tests relative to the other three groups. Further, many of those classified as “no deficit” by the CTOPP demonstrate impaired academic performance; apart from math deficits, 36.9% of ND students scored below the 16th percentile on WIAT Pseudoword Decoding, 31.6% on Word Reading, and 57.9% on Spelling. Further, almost half (46.3%) of the ND group performed below the 16th percentile on the TOWRE Pseudoword Decoding subtest, whereas only 12.2% showed such impairment on the sight word subset. Finally, 34.5% of the ND group had impaired Reading Fluency.

4 | DISCUSSION

Beyond identifying the existence of underlying deficit, specifying whether the deficits associated with dyslexia are based in a PAD or naming speed deficit adds less to our ability to predict or explain associated features than expected. As in many other studies, students with deficits in both phonological awareness and naming speed tend to

TABLE 2 Value of test scores as a function of dyslexia category

Test, subtest			Dyslexia categories (using 16th percentile cut score): No deficit	PA deficit	RN deficit	Double deficit
Wechsler Intelligence Scale for Children-IV						
Digit Span	$F(3, 146) = 1.108$ $\eta^2 = .022$	N M (SD)	42 7.36 (2.2)	22 7.68 (2.3)	48 7.81 (2)	38 7.03 (2)
Coding	$F(3, 145) = 4.674$ $\eta^2 = .088$		42 $8.57_{a,b}$ (2.8)	22 8.09 (2.9)	47 6.68_{a} (2.6)	38 6.92_{b} (2.8)
Symbol Search	$F(3, 146) = 2.059$ $\eta^2 = .041$		42 9.55 (3)	22 8.95 (3.1)	48 8.27 (2.6)	39 8.16 (2.9)
Processing Speed	$F(3, 146) = 4.246$ $\eta^2 = .080$		42 $95.19_{a,b}$ (15)	22 91.55 (14.2)	48 85.96_{a} (12.8)	39 85.92_{b} (14.1)
Working Memory	$F(3, 146) = 3.507$ $\eta^2 = .067$		42 89.9 (8.9)	22 88.32 (9.9)	48 90.75_{a} (9.7)	38 83.87_{a} (12.8)
Verbal Comprehension	$F(3, 146) = 1.260$ $\eta^2 = .025$		42 101.34 (15.7)	22 97.82 (12.2)	48 101.44 (9.8)	38 97.24 (11.6)
Perceptual Reasoning	$F(3, 146) = 3.481$ $\eta^2 = .051$		42 102.33 (14.1)	22 98.14 (13.1)	48 105.02 (11.4)	39 98.24 (12.7)
Full Scale IQ	$F(3, 145) = 3.958$ $\eta^2 = .076$		41 97.85_{a} (13.4)	22 93 (10.6)	48 96.27 (8.5)	38 90.08_{a} (10.6)
Wechsler Individual Achievement Test-II						
Word Reading	$F(3, 124) = 17.239$ $\eta^2 = .294$	N M (SD)	38 $90.47_{a,b,c}$ (9)	21 80.14_{a} (8.1)	37 $81.16_{b,d}$ (10.9)	32 $73.19_{c,d}$ (11.5)
Reading Comprehension	$F(3, 104) = 2.247$ $\eta^2 = .061$		28 97.11 (13.3)	20 90.45 (14.4)	28 95.43 (10.8)	24 89.38 (14.2)
Spelling	$F(3, 123) = 5.655$ $\eta^2 = .121$		38 $84.21_{a,b}$ (8.8)	21 77.9 (8.6)	36 78.14_{b} (10)	32 75.69_{a} (8.9)
Numerical Operations	$F(3, 86) = 4.315$ $\eta^2 = .128$		23 84.17_{a} (14.4)	15 78.67 (17.7)	27 76.7 (14)	25 69.32_{a} (12.8)
Math Reasoning	$F(3, 84) = 1.836$ $\eta^2 = .095$		24 96 (13.6)	15 92.13 (13.3)	24 93.08 (11.1)	25 87.2 (13.9)
Test of Word Reading Efficiency						
Phonemic Decoding	$F(3, 143) = 17.658$ $\eta^2 = .270$	N M (SD)	41 $86.93_{a,b}$ (8.3)	22 $81.6_{c,d}$ (7.6)	45 $77.06_{b,c}$ (7.5)	39 $74.84_{a,d}$ (8.7)
Sight Word	$F(3, 143) = 14.468$ $\eta^2 = .233$		41 $90.49_{a,b}$ (6.2)	22 $87.9_{c,d}$ (5.9)	45 $80.8_{b,c}$ (10.6)	39 $80.02_{a,d}$ (8.9)
Total	$F(3, 143) = 20.902$ $\eta^2 = .305$		41 $88.3_{a,b}$ (6.8)	22 $84.4_{c,d}$ (5.9)	45 $77.84_{b,c}$ (8.9)	39 $76.33_{a,d}$ (7.9)
Woodcock–Johnson III						
Visual Matching	$F(3, 79) = 0.994$ $\eta^2 = .036$	N M (SD)	21 80.43 (15.7)	14 82.29 (18.5)	24 79.33 (13.6)	24 74.38 (14.6)
Decision Speed	$F(3, 80) = 0.972$ $\eta^2 = .035$		21 95.62 (18.9)	14 96.43 (13.5)	25 95.28 (15.5)	24 88.83 (17.4)
Processing Speed	$F(3, 79) = 1.038$		21	14	24	24

(Continues)

TABLE 2 (Continued)

Test, subtest			Dyslexia categories (using 16th percentile cut score) No deficit	PA deficit	RN deficit	Double deficit
	$\eta^2 = .038$		85.6 (18.7)	85.14 (16.2)	85.17 (16.1)	78 (17.1)
Reading Fluency	$F(3, 94) = 7.025$ $\eta^2 = .183$		29 $89.48_{a,b}$ (10.9)	16 86.38 (8.6)	30 81.27_{a} (10.9)	23 77.87_{b} (7.4)
Wide-Range Assessment of Memory and Learning						
Verbal Memory	$F(3, 121) = 1.676$ $\eta^2 = .040$	*N* *M* (*SD*)	34 97.42 (12.4)	22 98.68 (11.5)	33 100.3 (9.4)	33 94.56 (9.5)
Visual Memory	$F(3, 118) = 0.455$ $\eta^2 = .011$		34 95.06 (12.8)	22 97.27 (13)	33 97.7 (13.8)	33 94.82 (9.1)
Gray Oral Reading Test IV						
Oral Reading Quotient	$F(3, 36) = 2.736$ $\eta^2 = .186$	*N* *M* (*SD*)	14 83.5_{a} (10.7)	9 78.67 (7.7)	8 78.25 (5.3)	9 70.44_{a} (15.6)
Comprehensive Test of Phonological Processing						
Phonological Awareness	$F(3, 150) = 81.325$ $\eta^2 = .619$	*N* *M* (*SD*)	42 $98.64_{a,b}$ (9.9)	23 $78.65_{a,c}$ (5.2)	48 $97.17_{c,d}$ (8.2)	41 $77.73_{b,d}$ (5.4)
Rapid Naming	$F(3, 150) = 83.882$ $\eta^2 = .627$		42 $95.24_{a,b}$ (7.2)	23 $95.57_{c,d}$ (8.1)	48 $74.6_{a,c}$ (8.5)	41 $72.85_{b,d}$ (9.3)
Delis–Kaplan Executive Function Scale						
Trails Visual Scan	$F(3, 29) = 0.673$ $\eta^2 = .065$	*N* *M* (*SD*)	9 8.56 (3.5)	4 6.5 (3.4)	12 8.08 (3.7)	8 9.5 (3.5)

Note. Values in the same row and sharing the same subscript are significantly different at $p < .05$. Cells with no subscript are not statistically different. Tests assume equal variances. Tests are adjusted for all pairwise comparisons using the Bonferroni correction. Means and significant differences are based on original reading deficit grouping.
Abbreviations: PA, phonological awareness; RN, rapid naming speed.

be the weakest readers. However, fewer differences between deficit groups emerged than might be expected if they truly represent different underlying causes of dyslexia. The PAD, RND, and DD adolescents in this study did not differ in overall FSIQ. All groups demonstrated substantially poorer than average phonetic decoding in terms of both accuracy and speed. In terms of underlying cognitive processing impairments, only auditory working memory was found to be more impaired in the DD group than in the other groups. With respect to academic functioning, few differences were found between the deficit groups; their untimed word reading, reading comprehension, and spelling skills all fell well below average. The DD group performed significantly worse than other groups on untimed word reading skills, and both the DD and RND groups performed equally but below the PAD group on measures of reading fluency and word decoding efficiency.

As suggested previously by Vukovic and Siegel (2006), results of the present study confirm that choice of classification method influences both group composition and deficit pattern found in adolescents with dyslexia. In the present study, using either the 16th percentile cut-off on the CTOPP or the *k*-means procedure resulted in at least one quarter of adolescents previously diagnosed with a dyslexia being classified as having both deficits, whereas using the 25th percentile as the marker for impairment resulted in almost 40% of the total sample being identified as having a DD. Contrary to prior studies that identified few individuals with deficits only in naming speed (Badian, 1997; Vukovic & Siegel, 2006), single naming speed deficits in our sample outnumbered single PADs at a ratio of two to one regardless of percentile score employed, at least when using the CTOPP as the method of group identification. Conversely, despite using the CTOPP scores alone as the method of group classification, the *k*-means clustering

TABLE 3 Students scoring below 16th percentile on achievement tests

	Number of students scoring below 16th percentile (by group)			
Test, subtest	No deficit	PA deficit	RN deficit	Double deficit
Wechsler Individual Achievement Test-II				
Word Reading	12/38 (31.6%)	14/21 (66.7%)	21/37 (56.7%)	28/32 (87.5%)
Pseudoword Decoding	14/38 (36.9%)	13/20 (65%)	21/37 (54.1%)	28/32 (87.5%)
Spelling	22/38 (57.9%)	17/21 (80.9%)	26/36 (72.2%)	27/32 (84.4%)
Numerical Operations	11/23 (47.8%)	10/15 (66.6%)	17/27 (62.9%)	23/25 (92%)
Math Reasoning	6/24 (25%)	3/15 (20%)	7/24 (29.2%)	11/25 (44%)
Test of Word Reading Efficiency				
Phonemic Decoding	34/39 (87.2%)	14/22 (63.6%)	39/45 (86.7%)	19/41 (46.3%)
Sight Word	24/39 (61.5%)	4/22 (18.2%)	28/45 (62.2%)	5/41 (12.2%)
Woodcock–Johnson III				
Reading Fluency	19/23 (82.6%)	6/16 (37.5%)	20/30 (66.7%)	10/29 (34.5%)

Abbreviations: PA, phonological awareness; RN, rapid naming speed.

method classified the majority of students as having phonological deficits with fewer students classified as having a rapid naming profile.

As predicted, those classified as having RND performed more poorly on speed-related tasks relative to the PAD group. When all four groups of reading disabled students were compared, it was clear that the DD group had, on average, the lowest scores on measures of word reading, working memory, and FSIQ, at least when using the 16th percentile and *k*-means classifications methods.

As suggested by Vukovic and Siegel (2006) in their review of the extant literature, our findings support that differences in the proportions of students classified as PA, RND, or DD in previous studies may be a function of factors such as the age of the sample, tasks used to classify students and level below which academic functioning is deemed impaired, or number of students with co-morbid ADHD. For instance, phonological deficits identified in younger children might be amenable to remediation such that by adolescence those who once had both deficits now evidence impairments only in rapid naming speed and those with phonological deficits alone now perform normally on those CTOPP tasks. Certainly, there is evidence that PADs are responsive to early remediation (Ehri et al., 2001; Lovett & Steinbach, 1997; Scanlon & Vellutino, 1997; Solis et al., 2012) and many mainstream classroom teachers may now provide such instruction. By contrast, numerous studies show "that naming speed is difficult to improve, and that students can improve in reading skills without accompanying improvements in naming speed" (Kirby et al., 2010, p. 354). It may be the case that some of the RND adolescents in our study would have presented DDs when they were younger, but their early diagnosis resulted in remediation of their phonological difficulties only. This notion is also supported by research showing that slow naming speed is one of the key characteristics that distinguishes those who respond to early intervention from those who do not (Al Otaiba & Fuchs, 2006; Kirby et al., 2010; Nelson, Benner, & Gonzales, 2003). It therefore makes sense that one might find a higher proportion of dyslexic students with continuing rapid naming deficits among a sample of adolescents who were first diagnosed in childhood. The students whose primary deficits were in phonological awareness in their earlier years may have been sufficiently remediated such that they were not even referred for assessment. In other words, younger samples of reading-impaired students may be more likely to contain a higher proportion of students with phonological awareness or DDs.

Classification is also likely to differ as a function of the tasks used to assess phonological and naming speed skills. In particular, some studies have used pseudoword decoding (rather than phonological processing) as the phonological classification measure. In our sample, over half of students demonstrated intact phonological awareness on the CTOPP, but deficient naming speed performed below the 16th percentile on WIAT Pseudoword Decoding and would have been classified within the DD category had WIAT Pseudoword Decoding been used as the phonological measure rather than the CTOPP. Similarly, just over a third of those with no deficit in CTOPP rapid naming skill performed below the 16th percentile on a separate reading fluency task. More importantly, a large per cent of the students deemed to have "no deficit" using the CTOPP 16th percentile cut score were impaired in one or more academic or processing task, and many more had skills that were between the 16th and 25th percentiles. In other words, adolescents who would not be classified as dyslexic using either deficit model were still found to be impaired on many reading-related tasks. Hence, use of only one test to classify children as dyslexic does not accurately capture the functional impairments they experience in real-world learning activities.

Consistent with our hypothesis, students with co-morbid ADHD would have also influenced the proportion of children identified as having rapid naming or DDs had they been included in the analyses; however, removal of those ADHD children from the present sample did not eliminate a large proportion of adolescents who were still classified as either RND or DD. Hence, co-morbid ADHD alone cannot explain the varying numbers of children previously classified as having rapid naming deficits.

Our findings show that although most adolescents with a history of dyslexia can be readily grouped, the group assignment does change depending on method employed. However, if employing the 25th or 16th percentile as an indicator of impairment on the CTOPP, the majority of students with dyslexia are classified as having either both deficits or a single deficit in naming speed. This suggests that practitioners concerned with identifying the processing deficit underlying a dyslexia must assess both types of skills, especially in adolescents or young adults. Assessment focused solely on PADs would fail to identify a large number of adolescents whose only current deficit is in naming speed. Given the recent emphasis on assessing phonological abilities, it seems likely that this is a common occurrence in our schools at present. Although there are many criterion-based tools that enable classroom and resource teachers to identify gaps in phonological awareness, identification of deficits in naming speed requires standardized testing, which is more likely to be conducted in the course of psychoeducational evaluations.

Relatedly, and similar to previous investigations of this nature, a significant number of adolescents in this study (anywhere from 15% to 27% depending on classification method) demonstrated neither phonological nor naming speed deficits on the CTOPP, and just under half were performing above the 25th percentile on tests of academic achievement. These students are worthy of further investigation. It is possible that they were identified previously based on phonological processing deficits that have since been adequately remediated. Future research should conduct longitudinal evaluations to better understand the reasons for improved performance in this latter group. These students may well represent early intervention successes who no longer require academic accommodations, something that has profound implications for providing long-term, unchanging academic accommodations for all students who were first diagnosed with dyslexia in childhood.

On the basis of our findings, it is possible to say that although either single deficit or DD may be identified in young adolescents with dyslexia, specification of the deficit primarily enhances our ability to predict only the level of reading difficulty (adolescents with DDs are likely to be the poorest readers) and speed of reading (adolescents with naming speed deficits and DDs are more likely to read individual words and connected text more slowly). Although these findings appear to add minimally to the explanation of dyslexia, several avenues must be explored further before the DD model is declared unhelpful in the clinical identification and treatment of dyslexia in adolescence.

4.1 | Limitations and future research directions

First, this research was based solely on scores earned on standardized tests. Although all of these showed adequate reliability and are commonly used in clinical practice, some are known to be inadequate on a number of fronts. For example, the spelling task does not distinguish between regularly spelled and irregularly spelled words. As a result, students may spell some words correctly using phonetic strategies rather than employing actual knowledge of the correct spellings. Furthermore, some skills were not measured at all (e.g., orthographic awareness) or were measured in a manner that does not allow for sufficient distinction between subskills (e.g., the role of basic math fact knowledge in written calculation). Inclusion of oral passage reading would also enable better error analysis. For example, though they make an equal number of errors, adolescents with PADs may demonstrate poor knowledge of sound–letter correspondences used in phonetic decoding, whereas those with naming speed deficits may make accurate associations but have more difficulty blending the sequence of sounds accurately.

Last, other possible co-morbid disorders that could affect phonological awareness or naming speed such as a specific language disorder were not investigated in this study. This would be an important area for future research to explore.

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