Published in final edited form as:
J Learn Disabil. 2013 ; 46(6): 500–516. doi:10.1177/0022219413477476.

Comorbidity between reading disability and math disability: Concurrent psychopathology, functional impairment, and neuropsychological functioning

Erik G. Willcutt,
University of Colorado at Boulder

Stephen A. Petrill,
The Ohio State University

Sarah Wu,
University of Colorado at Boulder

Richard Boada,
University of Colorado School of Medicine

John C. DeFries,
University of Colorado at Boulder

Richard K. Olson, and
University of Colorado at Boulder

Bruce F. Pennington
University of Denver

Abstract

Reading disability (RD) and Math Disability (MD) frequently co-occur, but the etiology of this comorbidity is not well understood. Groups with RD only (N = 241), MD only (N = 183), RD +MD (N = 188), and a control group with neither disorder (N = 411) completed a battery of measures of internalizing and externalizing psychopathology, social and academic functioning, and ten neuropsychological processes. Groups with RD only, MD only, and RD+MD were significantly impaired versus the control group on nearly all measures, and the group with RD +MD was more impaired than the groups with MD and RD alone on measures of internalizing psychopathology, academic functioning, and seven of ten neuropsychological constructs. Multiple regression analyses of the neuropsychological measures indicated that deficits in reading and math were associated with shared weaknesses in working memory, processing speed, and verbal comprehension. In contrast, reading difficulties were uniquely associated with weaknesses in phoneme awareness and naming speed, and math deficits were uniquely associated with weaknesses in set shifting. These results support multiple-deficit neuropsychological models of RD and MD, and suggest that RD and MD are distinct but related disorders that co-occur due to shared neuropsychological weaknesses in working memory, processing speed, and verbal comprehension.

Reading disability (RD) and math disability (MD) are common developmental disorders that are defined by significant academic underachievement that is unexpected based on an individual's age and development (e.g., American Psychiatric Association, 2000).

Address correspondence to: Erik Willcutt, Ph.D., Department of Psychology and Neuroscience, University of Colorado, Boulder, CO 80309, Telephone: (303) 492-3304, erik.willcutt@colorado.edu.

Interpretation of studies of RD or MD is complicated by the fact that RD and MD co-occur in 30 – 70% of individuals with either disorder, a phenomenon known as *comorbidity* (e.g., Badian, 1999; Kovas et al., 2007; Landerl & Moll, 2010; White, Moffitt, & Silva, 1992).

Despite strong evidence that RD and MD frequently co-occur, relatively few studies have systematically examined the causes or implications of comorbidity between RD and MD. To begin to address this gap in the literature, the current study compared groups of children and adolescents with RD only, MD only, RD + MD, and a comparison sample with neither disorder on an extensive battery of measures of comorbid psychopathology, functional impairment, and neuropsychological functioning. To set the stage for these analyses, we next describe several competing explanations for comorbidity between RD and MD, then briefly review the existing literature on RD, MD, and comorbid RD + MD in each of the domains included in the current study.

Competing explanations for comorbidity between RD and MD

Artifactual comorbidity

Before attempting to explain the cause of comorbidity between two disorders, it is essential to test whether the observed comorbidity is simply due to chance or is the result of a sampling artifact or shared method variance. RD and MD co-occur more frequently than expected by chance in a number of large population-based samples (e.g., Badian, 1999; Knopik, Alarcon, & DeFries, 1997; Kovas et al., 2007; Landerl & Moll, 2010), indicating that this comorbidity is not an artifact restricted to clinic samples. RD and MD could potentially co-occur due to shared method variance because they are typically defined by reading and math subtests from the same battery of standardized achievement tests. However, significant covariance has also been reported between parent and teacher ratings of reading or math difficulties and scores on standardized tests of the other domain (e.g., Kovas, Harlaar, Petrill, & Plomin, 2005; Willcutt et al., 2011), suggesting that the significant association between reading and math difficulties is robust across different methods of assessment.

Competing explanations for true comorbidity between RD and MD

Over a dozen competing explanations have been proposed to account for non-artifactual comorbidity between multifactorial disorders (e.g., Neale & Kendler, 1995; Rhee, Hewitt, Corley, Willcutt, & Pennington, 2005). We next provide a brief description of four of the most plausible models for comorbidity between RD and MD, and describe the specific predictions of each of these models for the 2 X 2 (RD X MD) design that is used in the current study.

The *alternate forms model* suggests that RD and MD are alternate manifestations of the same underlying etiological influences, with random factors determining whether an individual meets criteria for RD only, MD only, or RD + MD. Thus, this model makes the strong prediction that the three groups should have identical profiles of impairment on the measures of concurrent psychopathology, functional impairment, and neuropsychological functioning.

The *phenocopy model* proposes that one disorder leads to the phenotypic manifestation of the second disorder in the absence of the causal factors associated with the second disorder when it occurs in isolation. If this model is correct the profile of the comorbid group on external measures should be similar to the profile of the group with the first disorder alone. For example, if word reading difficulties in children with RD directly caused difficulties on a measure of math word problems that was then used to define MD, the comorbid group would have a phenocopy of MD that occurred despite the absence of weaknesses in processes such as number-sense that are typically associated with math difficulties.

The *three independent disorders model* suggests that RD + MD is a third disorder that is qualitatively distinct from RD or MD alone. This model would be supported if at least a subset of the weaknesses in the comorbid group are qualitatively distinct from the weaknesses in the groups with RD only or MD only.

Finally, the *correlated liabilities model* suggests that RD and MD co-occur more often than expected by chance due to shared etiological influences, whereas additional etiological influences specific to each disorder lead to the distinction between RD and MD. This model is supported by bivariate twin analyses, which suggested that comorbidity between RD and MD is due at least in part to common genetic influences (Knopik et al., 1997; Kovas et al., 2007; Willcutt, Pennington, et al., 2010). In addition to these shared risk factors, the twin analyses also indicated that separate genetic and environmental influences contribute independently to RD and MD. In the current study, the correlated liabilities model would be supported if a subset of underlying weaknesses and functional impairment are associated with weaknesses in both reading and math, whereas others are specific to RD or MD.

Studies of comorbid psychopathology

RD

In addition to comorbidity with MD, nearly half of all individuals with RD also meet criteria for at least one additional emotional or behavioral disorder (e.g., Goldston et al., 2007; Maughan, Rowe, Loeber, & Stouthamer-Loeber, 2003; Willcutt & Pennington, 2000). The most frequent comorbid disorder in groups with RD is attention-deficit/hyperactivity disorder (ADHD), and particularly the inattentive (ADHD-I) and combined (ADHD-C) subtypes of ADHD that are characterized by significant inattention (e.g., Willcutt, Betjemann, et al., 2010). Individuals with RD are also at higher risk for externalizing disorders such as oppositional defiant disorder (ODD) and conduct disorder (CD), but several studies suggest that associations between RD and antisocial behavior may be restricted to the subset of individuals with comorbid ADHD (e.g., Frick et al., 1991; Maughan et al., 2003; Willcutt & Pennington, 2000). In contrast, existing data suggest that RD is independently associated with higher rates of anxiety, depression, and suicidal ideation after controlling for symptoms of ADHD and other disruptive disorders (Daniel et al., 2006; Goldston et al., 2007; Maughan et al., 2003; Willcutt & Pennington, 2000).

MD

No previous studies have reported rates of comorbid mental disorders in groups with MD, but a handful have examined dimensional measures of specific aspects of psychopathology (e.g., Auerbach, Gross-Tsur, Manor, & Shalev, 2008; Badian, 1999; Cirino, Fletcher, Ewing-Cobbs, Barnes, & Fuchs, 2007; Shalev, Auerbach, & Gross Tsur, 1995; White et al., 1992; Willcutt et al., 2011). These studies suggest that individuals with MD exhibit significant elevations of attentional difficulties and internalizing and externalizing symptoms, although some studies reported that these effects were restricted to the subgroup with comorbid RD + MD (e.g., Badian, 1999; White et al., 1992).

Overall, the existing literature provides important preliminary evidence that both RD and MD may be associated with multiple dimensions of psychopathology. However, very few studies have included a group with RD + MD, and interpretation of studies of groups with MD only is constrained by small sample sizes, measures of psychopathology that do not map cleanly onto current diagnostic criteria, and the absence of a control group in several studies (Auerbach et al., 2008; Shalev et al., 1995). Additional research is needed to clarify

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which disorders co-occur with MD and to test whether rates of comorbid disorders differ in groups with RD only, MD only, and RD + MD.

Studies of functional impairment

RD

In comparison to individuals without RD, individuals with RD receive lower grades and report lower academic motivation, experience higher levels of academic frustration and are more likely to drop out prior to completing high school, and reach lower levels of educational and occupational attainment as adults (e.g., Boetsch, Green, & Pennington, 1996; Daniel et al., 2006; Goldston et al., 2007; McGee, Prior, Willams, Smart, & Sanson, 2002). In addition to these pervasive academic difficulties, several studies suggest that RD is also associated with smaller but significant weaknesses on measures of social functioning (e.g., Goldston et al., 2007; Willcutt et al., 2007; Willcutt et al., 2011), but none have tested whether these external correlates of RD vary as a function of comorbid MD.

MD

Surprisingly few studies have systematically examined whether MD is associated with significant academic or social impairment. White et al. (1992) reported that children with MD were more socially isolated than children without MD, but this effect was only observed in the group with RD + MD. Similarly, a more recent study reported that children with MD had weaker social cognition and were more socially anxious than a comparison group without MD, but this study did not control for comorbid RD (Willcutt et al., 2011).

A third group published a series of papers describing a longitudinal study of dyscalculia (Auerbach et al., 2008; Shalev et al., 1995; Shalev, Auerbach, Manor, & Gross-Tsur, 2000). Although their study did not include a control group, the authors were able to use normative data from the standardization sample for parent ratings on the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001) to determine how many individuals with persistent math difficulties exhibited “clinically-significant” elevations on each CBCL scale, as defined by a score that fell at or above the 98th percentile of the normative sample. In comparison to an expected base rate of 2%, a higher proportion of the MD group exhibited clinically significant levels of social withdrawal (11 – 21%) and overall social problems (11 – 25%).

A final line of research relevant to the psychosocial correlates of MD are the benchmark studies of nonverbal learning disability (NLD) conducted by Rourke and colleagues (e.g., Rourke, 1989). In these studies NLD was defined by weak math skills in comparison to intact word decoding and spelling ability, along with a more extensive profile of deficits that included weaknesses in social functioning, gross motor coordination, and higher-order cognitive processes such as spatial organization and executive control. Children with NLD often exhibited significant impairments in social cognition and reciprocity, leading to social isolation and elevations of withdrawn and internalizing behaviors. Interpretation of these results in relation to MD is complicated by the fact that the operational definition of NLD incorporated several criteria in addition to a specific weakness in math achievement, including specific aspects of social dysfunction. Nonetheless, in combination with the studies of MD reviewed in this section, these results provide additional support for the hypothesis that MD may be associated with significant social impairment, and underscore the need for further systematic research to clarify the psychosocial and academic correlates of MD with and without RD.

Studies of neuropsychological functioning

Until recently, neuropsychological models of complex disorders such as RD and MD typically proposed that a single primary neurocognitive deficit was necessary and sufficient to explain all of the symptoms of the disorder. However, data across multiple levels of analysis increasingly challenge the validity of single-deficit models (see Pennington, 2006 for a comprehensive review and discussion). From a theoretical perspective, models that posit a single primary cognitive dysfunction that is specific to each disorder cannot easily account for the pervasive comorbidity between RD and MD and nearly all other pairs of developmental disorders. This concern was underscored by a meta-analysis of neuropsychological studies of nine developmental disorders (Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008). Weaknesses on each of the 10 neuropsychological constructs that were included in the review were significantly associated with at least four of the nine disorders, and some weaknesses such as slow processing speed and increased response variability were significantly associated with all nine disorders.

These and other converging results have precipitated a significant reconceptualization of neuropsychological models of developmental disorders. Rather than attempting to identify a single neuropsychological weakness that is specific to each disorder, more recent theoretical models explicitly hypothesize that RD, MD, and other developmental disorders arise from the additive and interactive effects of multiple neuropsychological weaknesses (e.g., Geary, 2010; McGrath et al., 2011; Pennington et al., 2012; Willcutt et al., 2008). We next briefly review previous neuropsychological studies of RD and MD in the context of this multiple-deficit framework.

RD

Studies of individuals with and without RD suggest that phonological decoding, defined as the ability to translate sequences of printed letters into the corresponding sounds, plays a central role in both normal and abnormal reading development (Wagner, 1986; Wagner et al., 1997). Deficits in phonological decoding are in turn linked to genetic influences on the oral language skill of phoneme awareness, defined as the ability to recognize and manipulate the phonemic constituents of speech (Olson, Forsberg, & Wise, 1994). Problems with phoneme awareness are regarded by many as the most proximal cause of most cases of RD (e.g., Wagner, Torgesen, & Rashotte, 1994).

In addition to the well-documented relation between reading difficulties and different aspects of phonological processing, recent studies suggest that individuals with RD exhibit independent weaknesses in several other cognitive domains after group differences on phonological measures are controlled. These include weaknesses in verbal comprehension and other aspects of speech and language processing (e.g., Pennington & Bishop, 2009), slower verbal naming speed and general processing speed (e.g., Compton, DeFries, & Olson, 2001; Landerl, Fussenegger, Moll, & Willburger, 2009; Shanahan et al., 2006), increased response variability (Purvis & Tannock, 2000; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005), and impairment on a range of specific executive functions that include verbal working memory and response inhibition (Purvis & Tannock, 2000; Roodenrys, Koloski, & Grainger, 2001; Willcutt, Betjemann, et al., 2010; Willcutt et al., 2005). Taken together, these results provide strong support for multiple-deficit cognitive models of RD.

MD

Although fewer studies have examined the neuropsychological functioning of groups with MD, the existing literature suggests that MD is associated with a pronounced weakness in numerosity, the understanding of different conceptual properties of numbers (e.g., Cirino et al., 2007; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Geary, Hoard, Nugent, & Byrd-Craven, 2008). In addition, some studies have reported that groups with MD performed worse than groups without MD on measures of phonological processing (Geary et al., 2007), short-term and working memory (e.g., Passolunghi & Cornoldi, 2008; Raghubar, Barnes, & Hecht, 2010), set shifting (e.g., van der Sluis, de Jong, & van der Leij, 2004), and processing and naming speed (e.g., Andersson & Lyxell, 2007; Geary et al., 2007), although these weaknesses were not found in all studies (e.g., Landerl et al., 2009; van der Sluis, van der Leij, & de Jong, 2005). This overall pattern of results is also consistent with a multiple-deficit neuropsychological model of MD.

Impact of comorbidity

A small number of neuropsychological studies have compared groups with comorbid RD + MD and groups with each disorder alone (e.g., Cirino et al., 2007; Landerl et al., 2009; van der Sluis et al., 2004). Although results have been mixed, preliminary evidence suggests that deficits in phonological processing are uniquely associated with RD whether or not an individual also has MD, whereas MD is uniquely associated with weak number-sense (e.g., Rosselli, Matute, Pinto, & Ardila, 2006). In contrast, individuals with comorbid RD + MD may be more impaired than individuals with RD or MD alone on some measures of response variability and working memory (Cirino et al., 2007; Landerl et al., 2009; van der Sluis et al., 2005). However, additional systematic research is needed in studies that include all three groups with RD or MD before any definitive conclusions can be drawn.

The current study

As part of the ongoing Colorado Learning Disabilities Research Center (CLDRC) twin study, groups with RD only, MD only, RD + MD, and a control group with neither disorder completed an extensive battery of measures of internalizing and externalizing psychopathology, functional impairment, and neuropsychological functioning. This is one of the first studies to examine diagnostic comorbidity and functional impairment in groups with MD, and one of only a handful of studies to use a full 2 X 2 (RD X MD) design to compare the neuropsychological functioning of groups with RD only, MD only, and RD + MD. Specific predictions were as follows:

1. Based on our previous results for RD, we anticipated that groups with RD only, MD only, and RD + MD would have higher rates of ADHD and all internalizing and externalizing disorders than the group without RD or MD. However, we expected elevations of externalizing disorders to be restricted to the subset of individuals with RD or MD who also met criteria for ADHD.

2. Based on the reading and math weaknesses that define the groups, we anticipated that all three groups with RD and MD would exhibit significant academic impairment. Further, we predicted that these academic difficulties would be most pronounced in the RD + MD group, and would not be explained by comorbid ADHD. In contrast, participants in all groups were expected to exhibit only modest impairment on measures of social functioning, especially if they did not meet criteria for comorbid ADHD.

3. The 28 tests in the neuropsychological battery measured 10 cognitive constructs that were significantly associated with RD or MD in previous studies. Based on the pervasive neuropsychological deficits observed for most developmental disorders in earlier meta-analyses (e.g., Willcutt et al., 2008), we predicted that groups with RD only, MD only, and RD + MD would exhibit significant deficits on all neuropsychological measures in comparison to the group without RD or MD. To

clarify which of neuropsychological constructs were independently associated with weaknesses in reading or math, multiple regression analyses were conducted to test which of the neuropsychological composites independently predicted reading or math scores after controlling for associations with the other cognitive constructs. We tentatively predicted that weaknesses in working memory, verbal comprehension, and processing speed would emerge as significant shared weakness in groups with RD only, MD only, and RD + MD. In contrast, we expected phonological processing difficulties to be associated with RD but not MD, and anticipated that only the groups with MD would exhibit a specific weakness in set shifting.

Method

Participants

Recruitment and testing procedures for the CLDRC are described in detail in previous papers (e.g., Shanahan et al., 2006; Willcutt et al., 2005), and are summarized more briefly here.

Initial screening—All twins enrolled in 22 local school districts were invited to participate in the initial screening for the study. Although twins between 8 and 18 years of age were screened for the overall study, the current analyses were restricted to participants between 8 and 15 years old due to the small number of participants with complete data who were 16 years of age or older. If either of the twins exhibited a significant history of attention or learning difficulties during the screening, the pair was invited to participate in the full study. In addition, a comparison sample was recruited from the remaining twin pairs in which neither twin exhibited a significant history of learning or attentional difficulties.

Due to the primary focus of the overall CLDRC study, pairs in which at least one twin exhibited significant reading and/or attentional difficulties were oversampled (approximately 67% of the final tested sample) to increase statistical power for analyses of extreme groups. To test the impact of this sampling procedure we first conducted the analyses in the entire sample. We then repeated the analyses after randomly selecting a subset of the pairs at risk for attention or learning problems to reconstitute a sample with the same proportions of pairs in the at-risk and control groups as were observed in the original population. All point estimates and effect sizes were extremely similar in the two sets of analyses (no difference in effect sizes larger than $g = 0.05$ for any analysis), and the overall pattern of results was nearly identical. Therefore, to maximize statistical power and simplify interpretation we present the results of analyses of the entire sample.

Exclusion criteria—CLDRC staff conducted a telephone screening interview with one of the parents of the twins prior to any testing. Potential participants with a documented brain injury, significant hearing or visual impairment, or a rare genetic or environmental etiology (e.g., Fragile X syndrome, Down syndrome or other sex chromosome anomalies) were excluded from the sample. Pairs were also excluded if either twin had received a diagnosis of psychosis, bipolar disorder, or pervasive developmental disorder.

Operational definitions of RD and MD—RD was defined by a cutoff score 1.25 SD below the estimated population mean (approximately the 10th percentile) on an age-adjusted composite measure of word reading derived from the Peabody Individual Achievement Test (PIAT) Reading Recognition subtest (Dunn & Markwardt, 1970) and a time-limited word reading test (Olson, Forsberg, Wise, & Rack, 1994). Similarly, MD was defined by a score 1.25 SD below the estimated population mean on a composite measure of math calculations derived from the Math subtests on the PIAT and the Wide Range Achievement Test, Revised (WRAT-R; Jastak & Wilkinson, 1984).

Although the DSM-IV definitions of RD and MD suggest that an individual's reading or math achievement must be significantly discrepant from their overall intelligence, the use of IQ scores as part of the diagnostic criteria for LDs is a long-standing area of controversy, and most experts argue against the use of an IQ-discrepancy criterion (Fletcher, Francis, Rourke, Shaywitz, & Shaywitz, 1992; Pennington, Gilger, Olson, & DeFries, 1992). Therefore, other than excluding participants with a Full Scale IQ score below 75 on the Wechsler Intelligence Scale for Children, Revised (Wechsler, 1974) to screen out participants with more significant general cognitive impairments, general cognitive ability was not included in the definitions of RD or MD.

Finally, because twins in a pair are not independent observations, one twin was randomly selected from each pair in which both twins met inclusion criteria for one of the groups. The final sample included 241 individuals with RD only (102 female; 42%), 183 individuals with MD only (101 female; 55%), 188 individuals with RD + MD (89 female; 47%), and a comparison group of 419 individuals without RD or MD (217 female; 52%). The overall sample was 80% Caucasian, 11% Hispanic, 4% African American, 3% Asian American, and 2% American Indian/Native American, and there were no significant group differences in sex ratio, race/ethnicity, or age.

Descriptive characteristics of the sample—As expected based on the procedures used to define the groups, both groups with RD exhibited pronounced weaknesses on all reading measures (Hedges' $g = 2.8 – 3.3$), and both groups with MD exhibited large deficits on both math measures ($g = 1.9 – 2.5$; Table 1). Importantly, the group with comorbid RD + MD scored significantly lower than the MD-only group on the math measures and lower than the RD only group on the reading measures ($g = .3 – .5$), replicating previous studies that found that the comorbid group had more severe reading and math deficits than the groups with RD or MD alone (e.g., Fletcher, Lyon, Fuchs, & Barnes, 2007). In addition, the groups with MD only and RD only scored significantly lower on the other academic dimension in comparison to the control group (Table 1; $g = 0.8 – 1.2$), indicating that participants with RD only and MD only exhibit subthreshold difficulties on the other academic dimension even if they do not meet full criteria for the other disorder. These two results are consistent with theoretical models that suggest that the diagnostic cutpoints specified for complex categorical disorders such as RD and MD dichotomize a continuous distribution of underlying liability to each disorder, and that these thresholds are more conventional than natural (e.g., Shaywitz, Escobar, Shaywitz, Fletcher, & Makuch, 1992; Willcutt, Pennington, & DeFries, 2000). Therefore, both categorical and continuous analyses were completed to fully describe the current data (described in detail in the data analysis section).

Procedures

Measures of general cognitive ability, reading and math achievement, processing speed, and component reading and language skills were administered in two testing sessions at the University of Colorado Department of Psychology and Neuroscience and Institute for Behavioral Genetics. The remaining neuropsychological tasks and measures of psychopathology and functional impairment were completed during a third session scheduled two to four weeks later at the University of Denver Department of Psychology. Each session lasted approximately two and one-half hours, and frequent breaks were provided to minimize fatigue and maximize motivation. All measures were administered by trained examiners who had previous experience working with children, and examiners were unaware of the diagnostic status of the child and the results of the testing completed in the other sessions.

Measures

The current analyses incorporated information from over 60 measures to maximize the reliability of summary scores that were computed for each construct of interest. Because space constraints preclude a full description of all measures, abbreviated descriptions are provided for measures that were described in detail in previous publications (Shanahan et al., 2006; Willcutt et al., 2007; Willcutt & Pennington, 2000; Willcutt et al., 2005). For constructs that were assessed by multiple measures, a composite score was created by computing the mean of age-regressed standardized scores on all measures of the construct, then restandardizing the resulting mean score.

Measures of psychopathology

ADHD—Parents and teachers rated the nine DSM-IV inattention symptoms and nine DSM-IV hyperactivity-impulsivity symptoms on the *Disruptive Behavior Rating Scale* (DBRS; Barkley & Murphy, 1998), and the ratings were then combined using the algorithm from the DSM-IV field trials (Lahey et al., 1994) to create inattention and hyperactivity-impulsivity symptom counts. ADHD classifications were based on full DSM-IV diagnostic criteria, including onset of symptoms before age seven and significant functional impairment across multiple settings. Participants were classified as DSM-IV Combined Type (ADHD-C) if they exhibited six or more symptoms of both inattention and hyperactivity-impulsivity. Twins who exhibited six or more symptoms of inattention but fewer than six symptoms of hyperactivity-impulsivity were coded as predominantly inattentive type (ADHD-I), and those with six or more symptoms of hyperactivity-impulsivity and fewer than six symptoms of inattention were classified as predominantly hyperactive-impulsive type (ADHD-H).

Internalizing and externalizing symptoms—Parents completed modules of the Diagnostic Interview for Children and Adolescents (e.g., Reich, Welner, & Herjanic, 1997) for DSM-IV oppositional defiant disorder (ODD), conduct disorder (CD), major depressive disorder (MDD), and generalized anxiety disorder (GAD). In addition, parents and teachers completed the Achenbach Scale for Empirically Based Assessment (ASEBA; Achenbach & Rescorla, 2001), a widely-used psychopathology screening measure. To simplify interpretation, a standardized composite measure was created for each ASEBA scale by computing the mean of age-regressed standardized scores for parent and teacher ratings.

Measures of academic, social, and overall functioning

Global functioning—Parents completed the non-clinician version of the Child Global Assessment Scale (Setterberg, Bird, & Gould, 1992), a measure of global impairment that asks raters to indicate the single number between 1 and 100 that best represents the individual’s current functioning. In addition, items on the DBRS asked parents and teachers to rate the extent to which the twin experienced difficulty with the overall management of daily responsibilities.

Academic functioning—As part of the DBRS parents and teachers rated the extent to which each participant experienced overall academic difficulties or had trouble understanding assignments and completing daily academic responsibilities. They also reported the participant’s current grades in reading, math, and English/language arts, and indicated whether the twin had received extra academic support in any of these areas. Finally, the twins were asked whether they found reading, math, or English to be difficult and rated the extent to which they like school.

Social functioning—Multiple measures were administered to facilitate the assessment of different dimensions of social functioning. The ASEBA Social Problems and Withdrawn scales provided measures of overall social impairment and social withdrawal, and parent ratings on the Social Isolation scale from the Colorado Learning Difficulties Questionnaire (CLDQ; Willcutt et al., 2011) assessed the child's tendency to become isolated or anxious in social settings. Finally, teachers estimated the proportion of children who like, dislike, or ignore the participant using the procedure described by Dishion (1990).

Neuropsychological Measures

The 28 tasks in the neuropsychological battery included measures of most of the constructs that were most strongly associated with RD or MD in previous studies. Scores on the individual measures of each construct were combined to create standardized composite scores for 10 neuropsychological constructs.

Phoneme Awareness—The *phoneme deletion tas*k requires participants to say what results when a phoneme is removed from a spoken nonword or real word (Olson, Forsberg, Wise, et al., 1994), and the *Pig Latin task* requires the child to move the first phoneme of a spoken word to the end of the word, then add the sound "ay" (Olson, Wise, Conners, Rack, & Fulker, 1989).

Verbal Comprehension—The WISC-R Verbal Comprehension score is a composite measure of the Vocabulary, Similarities, Information, and Comprehension subtests.

Response Inhibition—The *Stop-signal Task* is a computerized task that provides an estimate of stop-signal reaction time, a measure of the latency of the inhibitory process (e.g., Logan, Schachar, & Tannock, 1997). On primary task trials the participant presses a key in response to the appearance of the letters X or O on the monitor, then must inhibit their response if an auditory tone occurs shortly after the letter appears. The *Gordon Diagnostic System* (Gordon, 1983) is an 18-minute visual continuous performance test (CPT). Single-digit numeric stimuli are presented one per second, and the participant responds by pressing a large button when a 9 appears immediately after a 1. The primary measure of inhibition is the number of commission errors in response to a sequence of numbers other than the target.

Working memory—Three measures were used to create a composite measure of verbal working memory. In the *Sentence Span Task* (Siegel & Ryan, 1989) the participant provides the last word for a set of simple sentences read by the examiner (e.g., "I throw the ball up and then it comes…"), then must reproduce the words that they provided after all sentences in that set are completed. Similarly, the *Counting Span Task* (Case, Kurland, & Goldberg, 1982) requires the participant to count aloud the number of dots on a series of cards, then recall the number of dots on each card in the set. Finally, the Digits Backward component of *WISC-R Digit Span* (Wechsler, 1974) requires the participant to repeat in reverse order a series of numbers presented aloud by the examiner.

Set shifting—The *Wisconsin Card Sorting Test* (Heaton, 1981) measures the ability to flexibly shift cognitive set when the rules of the task are changed without warning. The primary dependent measure is the number of perseverative errors, in which the participant continues to respond based on the rule that was previously correct, rather than switching to the new rule.

Interference Control—Each trial of the *Stroop Color and Word Test* (Golden, 1978) required the participant to complete as many stimuli as possible in 45 seconds. On the Word trial the participant reads the names of colors (red, blue, and green) printed in black ink, and the subsequent Color trial requires the participant to name the color of non-linguistic patches of red, blue and green ink. The final trial introduces interference by presenting the words *red*, *blue*, and *green* printed in a different color of ink, and the participant is told to ignore the word and name the color of the ink. An interference control score was calculated by subtracting the age-corrected and standardized score on the interference trial from the restandardized mean of the age-corrected and standardized scores on the Word and Color trials.

Vigilance—The primary measures of vigilance is the number of omission errors (failure to respond to the target sequence) during the visual CPT described earlier (Gordon, 1983).

Processing Speed—A composite processing speed score was created by averaging the standardized scores on four measures that loaded on a latent processing speed factor in earlier analyses (McGrath et al., 2011). The *WISC-III Symbol Search* (Wechsler, 1991) and *WISC-R Coding* (Wechsler, 1974) subtests are widely-used psychometric measures of processing speed. On the *Colorado Perceptual Speed Test* (DeFries, Singer, Foch, & Lewitter, 1978) the participant circles one of four possible letter strings to match a target letter string as rapidly as possible. Similarly, the *Educational Testing Service Identical Pictures subtest* (French, Ekstrom, & Price, 1963) requires the participant to identify as quickly as possible the one picture out of five options that is an exact match to a target picture.

Naming Speed—The *Rapid Automatized Naming Test* is an adaptation of the measure developed by Denckla and Rudel (Denckla & Rudel, 1976). On each of the four test trials the participant names as many objects, numbers, letters, or colors as possible in 15 seconds. The mean of the standardized scores on the four trials was calculated and restandardized to provide a composite measure of naming speed.

Response variability—The primary measure of response variability is the intraindividual standard deviation of reaction times on the primary task trials of the stop-signal task.

Data analyses

Standard procedures were used to identify and adjust any observed outliers prior to any analyses (Willcutt et al., 2005). The distribution of each variable was then assessed for significant deviation from normality, and a logarithmic transformation was implemented to approximate a normal distribution for variables with skewness or kurtosis greater than one. As expected, correlational analyses revealed that performance on all neuropsychological measures improved as a function of age ($p < .01$ for all measures). Therefore, after each measure was cleaned and any necessary transformations were completed, an age-adjusted score was created by regressing the variable onto age and age-squared and saving the residual score. Due to the large number of statistical tests required to compare the groups across the extensive test battery, an alpha of .01 was adopted as the threshold for statistical significance, and *p*-values between .05 and .01 are described as marginally significant.

Primary analyses—Two complementary sets of analyses were used to examine the relation between reading, math, and the external measures. Because one of the primary goals of this paper and the overall special issue was to examine the relation between groups with RD and MD, analyses of variance (ANOVA) and chi-square tests were used to compare means and proportions in the four categorical groups with and without RD and MD. However, interpretation of these group comparisons was complicated by the greater severity of the reading and math deficits in the comorbid group in comparison to the groups with RD or MD only, along with the subclinical weaknesses on the other academic dimension in the groups with RD or MD alone. Therefore, a parallel series of dimensional analyses were also conducted that would not be affected by these issues. For each external measure, a multiple linear or logistic regression model was fitted in which the external measure was predicted by the continuous composite measures of reading and math and their interaction. Tables 2 – 5 summarize results of both sets of analyses.

Potential confounding variables—Zygosity and parental years of education were included as covariates in initial models, but were dropped from final models because neither variable had a significant impact on any result. Potential differences in the pattern of results as a function of age or sex were examined by testing for differences in males and females and in subsets of the sample age 11 or younger versus age 12 and older. The pattern of results was similar in males and females and in the two age groups, and no Sex X Group or Age X Group interactions were significant. Therefore, results are reported for the full sample.

As described earlier, weaknesses in reading and math are significantly associated with general cognitive ability, and previous studies suggest that comorbid symptoms of ADHD may mediate the relations between RD and MD and at least a subset of important external correlates. Some researchers have argued that it is important to control for these correlated variables to test whether any observed associations are specific to RD or MD and cannot be explained more parsimoniously by individual differences in intelligence or concurrent symptoms of ADHD (e.g., Lahey et al., 1998). In contrast, others point out that this approach makes the debatable assumption that intelligence has special status in comparison to other constructs, and that the decision to statistically control Full Scale IQ scores, ADHD symptoms, or other similar correlated variables may inadvertently remove meaningful variance related to reading or math (e.g., Dennis et al., 2009).

These issues have not been resolved conclusively, and the optimal approach may vary depending on the specific research question. Therefore, to provide a comprehensive description of our results, the initial set of analyses included only the measures of reading and math. If any effects in the initial model were significant, the analysis was repeated with Full Scale IQ and ADHD symptoms included as covariates, and results of both sets of analyses are reported in Tables 4 – 6.

Testing multiple-deficit neuropsychological models—As described earlier, a final series of analyses were conducted to test which neuropsychological weaknesses were independently associated with RD or MD. Rather than including each of the neuropsychological measures as a dependent variable in a separate analysis, all of the neuropsychological measures were included simultaneously in multiple regression models predicting the reading and math composites.

Results

Comorbid psychopathology

In comparison to participants without RD or MD, participants with RD only, MD only, and RD + MD exhibited more internalizing and externalizing symptoms and more symptoms of ADHD, and were more likely to meet diagnostic criteria for ADHD-C, ADHD-I, ODD, CD, GAD, and MDD (Table 2). Comparisons among the three LD groups indicated that the group with RD + MD exhibited more inattentive and internalizing symptoms and a higher rate of ADHD-I, MDD, and GAD than the groups with RD or MD alone. Multiple regression analyses revealed significant independent associations between reading and math and nearly all measures of psychopathology, although a subset of these effects were only marginally significant. Only one interaction was significant in the regression analyses, suggesting that the higher rates of comorbid disorders in the group with RD + MD reflect the additive combination of the main effects of math and reading.

Based on our previous finding that comorbid ADHD may at least partially account for associations between RD and some other disorders (e.g., Willcutt et al., 2007; Willcutt & Pennington, 2000), secondary analyses were then conducted to test whether rates of comorbid psychopathology differed when groups with RD only, MD only, and RD + MD were subdivided as a function of comorbid ADHD (Figure 1). In all three groups comorbidity with ODD and CD was restricted to the subset of cases that also meet criteria for ADHD. In contrast, groups with RD only, MD only, and RD + MD had significantly higher rates of depression whether or not they met criteria for ADHD, although the rate of depression was significantly higher in the group with both RD and ADHD than the group with RD alone (Figure 1 panel B). Results for GAD were mixed; in the group with MD only the subset with comorbid ADHD exhibited significantly higher rates of GAD (Figure 1 panel A), whereas in both groups with RD the rate of comorbid GAD was similar in subgroups with and without ADHD (Figure 1 panels B and C).

Functional impairment

Academic functioning—Groups with RD only, MD only, and RD + MD were significantly impaired on all measures of academic functioning in comparison to the group without RD or MD (Tables 3 and 4), and multiple regression analyses confirmed that main effects of math and reading were both significant for all measures with the exception of the relation between reading achievement and self-reported difficulty in math. The vast majority of participants with RD or MD reported significant difficulty in the academic domain that defined their learning disability, and nearly half of the participants in the groups with RD only and MD only also reported significant difficulty in the other academic domain (Table 3).

Comparisons among the RD and MD groups indicated that the two groups with RD had lower average grades and overall academic functioning than the group with MD only, and the comorbid group had lower grades than any of the other groups (Table 4). Although information regarding academic interventions was not available for the entire sample, results in a subset of the sample indicated that the majority of individuals with RD had received extra help in reading (69%). A similar percentage of the RD + MD group had also received extra help in math (61%), whereas a significantly smaller proportion of the group with MD only had received assistance in math (37%; Table 3).

Global functioning—All three groups were also significantly impaired on the CGAS measure of global functioning and on parent and teacher ratings of the participant’s ability to manage daily responsibilities (Table 4). In addition, the group with RD + MD was more impaired than the groups with RD only and MD only on both measures, and the marginally significant interactions in the multiple regression analyses suggest that individuals with weaknesses in both domains may experience greater global impairment than would be expected based on the additive combination of the main effects of reading and math.

Social functioning—All three groups were associated with significant social impairment on all measures (Table 4). Multiple regression analyses suggested that math difficulties were more strongly associated than reading weaknesses with increased social isolation and less frequent positive interactions with peers, and significant interactions indicated that these effects were particularly pronounced among children with weaknesses in both math and reading. In contrast, individuals with reading weaknesses were more likely to be actively disliked by peers, but this effect was explained by concurrent symptoms of ADHD.

Neuropsychological measures

With two exceptions, the groups with RD only, MD only, and RD + MD performed significantly worse than the group without RD or MD on all neuropsychological measures, and these effects remained significant when ADHD symptoms and FSIQ were controlled (Table 5). In the first exception to this overall pattern, only the groups with math difficulties exhibited a significant weakness on the measure of set shifting, and the small but significant negative effects on the Stroop interference score indicated that the groups with reading difficulties actually performed significantly better than the control group. This pattern of results may have occurred because word reading is less automatic for individuals with RD, and therefore interferes less with color naming on trials with conflicting information.

Comparisons among the groups with RD or MD indicated that the comorbid group was more impaired than the groups with either disorder alone on seven of the ten neuropsychological composites. In most of these cases the interaction term in the multiple regression analysis of the continuous reading and math measures was not significant, suggesting that the greater impairment in the comorbid group primarily reflects the additive combination of the neuropsychological weaknesses associated with reading and math.

Multiple deficit models—Because weaknesses in reading and math were associated with significant weaknesses on nearly all of the neuropsychological measures, a final set of linear regression analyses was conducted to test which cognitive constructs independently predicted reading or math deficits (Table 6). Weaknesses in verbal comprehension, working memory, and processing speed were significantly associated with both reading and math. In addition to these shared weaknesses, reading difficulties were uniquely associated with phoneme awareness and naming speed, and math deficits were independently associated with difficulty shifting cognitive set. All of these effects remained significant when Performance IQ, ADHD symptoms, and the composite measure used to define the other learning disorder were included as covariates (Performance IQ was used to control for general cognitive ability for this analysis because Full Scale IQ includes the Verbal Comprehension subtests).

Discussion

This study systematically compared groups with RD only, MD only, RD + MD, and a comparison group without RD or MD on an extensive battery of measures of internalizing and externalizing psychopathology, social and academic functioning, and neuropsychological performance. Groups with RD only, MD only, and RD + MD were significantly impaired in comparison to the control group on most measures, and the comorbid group was more impaired than the groups with RD only and MD only in several domains. Although these overall results suggest that weaknesses in reading and math are both associated with impairment in many of these functional domains, results also revealed several important differences in the correlates of RD and MD. In the next three sections we discuss the results in each domain in more detail.

Comorbid mental disorders

Rates of ODD and CD were significantly higher in both groups with RD, but secondary analyses indicated that this comorbidity was restricted to the subset of probands who also met criteria for ADHD. In contrast, participants with reading difficulties exhibited higher rates of MDD and GAD whether or not they met criteria for ADHD, adding to a growing literature indicating that RD is associated with depression and other internalizing symptoms (e.g., Daniel et al., 2006).

This is the first study to report rates of comorbidity between MD and DSM-IV disorders. Rates of ADHD, ODD, CD, GAD, and MDD were all higher in groups with MD than in the comparison group without RD or MD. However, similar to the findings for RD, the association between MD and disruptive disorders (ODD and CD) was restricted to the subset of cases with comorbid ADHD.

Finally, this is also the first study to test whether rates of psychopathology differed in the group with both RD and MD versus the groups with RD and MD alone. Although there were no differences in rates of ODD and CD among the three groups, the group with RD + MD was more likely than any other group to meet criteria for GAD and MDD, and there was a significant Reading X Math interaction in miltiple regression analyses of internalizing symptoms. These results suggest that the combination of reading and math weaknesses may have synergistic effects that lead to internalizing symptoms.

Functional impairment

Not surprisingly, both RD and MD are associated with important negative academic outcomes that range from lower grades to increased risk of retention. Parents reported that the majority of the participants with reading difficulties had received extra academic help to address these concerns, whereas only 37% of the participants who met criteria for MD only had received extra academic assistance. This pattern is consistent with the results of another recent study that reported that children with RD + MD were five times more likely than children with MD only to have been identified as disabled by their school (Powell, Fuchs, Fuchs, Cirino, & Fletcher, 2008). These converging results suggest that additional research is needed to determine whether individuals with MD only receive adequate academic assistance.

Although the effects were not as large as the pervasive weaknesses on measures of academic functioning, all three groups with RD or MD also exhibited significant social difficulties in comparison to the group without RD or MD. Further, significant interactions in the multiple regression analyses suggested that individuals with weaknesses in both reading and math may be at especially high risk for friendship difficulties and social isolation. These results replicate the preliminary results reported in previous studies of MD (e.g., Shalev et al., 2000; Willcutt et al., 2011), and suggest that clinicians should routinely screen for social difficulties as part of a comprehensive assessment of RD or MD.

Neuropsychology of RD and MD: Support for multiple-deficit models

Each of the neuropsychological measures in the current battery was included in previous studies of RD or MD, but the current study is the first to analyze all of these domains in the same sample. The current results replicated the finding that deficits in phoneme awareness are the strongest neuropsychological predictor of RD (e.g., Wagner, 1986), but reading difficulties were also independently predicted by weaknesses in verbal comprehension, naming speed, processing speed, and working memory. A similar pattern emerged in multiple regression analyses predicting math difficulties, which were independently associated with weaknesses in verbal comprehension, working memory, set shifting, and processing speed. Overall, these results strongly support the need for the development of comprehensive multiple-deficit cognitive models of RD and MD (e.g., Pennington, 2006).

Implications for models of comorbidity between RD and MD

The significant co-occurrence of RD and MD in the current school-based sample provides additional evidence that comorbidity between RD and MD is not a clinical selection artifact. Although the current results indicate that groups with RD only, MD only, and RD + MD exhibited significant weaknesses on nearly all neuropsychological measures, mutiple regression analyses suggest that the neuropsychological profiles are at least partially distinct. Weaknesses in verbal comprehension, working memory, and processing speed were strongly associated with both reading and math when all neuropsychological measures were included as predictors in the model. In contrast, weaknesses in phoneme awareness and naming speed were independently associated with difficulties in reading but not math, whereas only math difficulties were associated with independent weaknesses in the ability to shift cognitive set. These distinct profiles confirm that RD and MD are separate disorders and provide strong evidence against the alternate forms hypothesis, which suggested that RD and MD are simply alternate manifestations of the same underlying pathophysiological dysfunction.

The group with comorbid RD + MD exhibited equal or greater impairment than the groups with RD only and MD only on nearly all measures that were impaired in the groups with RD or MD alone, and the comorbid group was significantly more impaired than the groups with RD only and MD only on measures of global functioning, academic functioning, and seven of the ten neuropsychological measures in the battery. These findings provide strong evidence to reject the hypotheses that either RD or MD leads to a secondary phenocopy of the other disorder in the absence of the risk factors typically associated with the secondary disorder when it occurs in isolation.

Finally, dimensional multiple regression analyses indicated that the main effects of reading and math were significant for most measures. Significant interactions on a handful of measures indicated that individuals with weaknesses in both reading and math exhibited greater impairment than would be expected based on the additive combination of the two main effects. However, in most cases the greater impairment in the comorbid group appeared to reflect the additive combination of the main effects of reading and math, arguing against the hypothesis that RD + MD is a third disorder that is distinct from RD or MD alone.

Overall, the current results provide the strongest support for a correlated liabilities model in which shared weaknesses in working memory, verbal comprehension, and processing speed increase risk for both RD and MD. In contrast, the two dimensions and disorders are distinguished by distinct profiles of weaknesses on measures of phoneme awareness, naming speed, and set shifting.

Limitations and future directions

Measurement of RD and MD—Because the CLDRC study has been ongoing for nearly 25 years, the PIAT and WRAT-R have been retained to allow comparisons to be made across the entire sample. Scores on the PIAT Reading Recognition and Math subtests and the WRAT-R Arithmetic subtest are highly correlated with the corresponding subtests on subsequent editions of the PIAT and WRAT (Markwardt, 1989; Wilkinson, 1993), suggesting that similar results would be obtained if newer measures were used. Nonetheless, future studies of groups defined by newer measures of math and reading achievement would provide an important replication of the current findings.

The current results provide important information regarding the neuropsychological and functional correlates of deficits in word reading and math calculations. However, behavior genetic analyses of a wider range of measures of reading and math suggest that results might differ if groups were defined by deficits on measures of reading comprehension, word problems, or reading or math fluency (e.g., Betjemann et al., 2008; Cutting, Materek, Cole, Levine, & Mahone, 2009; Hart, Petrill, & Thompson, 2010; Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006; Petrill et al., 2012). Future studies of these additional aspects of math and reading would also provide a useful extension of the current results.

Other cognitive measures—Although the rich battery of cognitive measures is a significant strength of the current study, specific measures of numerosity were added to the battery only recently, and were not available for the current analyses. Much like the critical role of phonological processing in reading development, the development of specific aspects of number-sense appears to play a critical role in the development of mathematical ability, and may be an additional dimension of cognition that is specifically associated with MD (e.g., Geary et al., 2008; Rosselli et al., 2006).

Conclusions

The current results indicate that groups with RD only, MD only, and RD + MD exhibit significant academic and social impairment and weaknesses in nearly all neuropsychological domains, with the most pronounced impairment exhibited by the group with RD + MD. Multiple regression analyses indicated that all three groups with RD or MD exhibited significant weaknesses on measures of processing speed, working memory, and verbal comprehension after controlling for associations with the seven other neuropsychological constructs. In contrast, deficits in phonological processing and naming speed were uniquely associated with reading difficulties, whereas difficulty shifting cognitive set was specifically associated with deficits in math. Taken together, these results suggest that RD and MD are separate but correlated disorders that sometimes co-occur due to shared genetic or environmental risk factors that lead to weaknesses in verbal comprehension, processing speed, and working memory.

Acknowledgments

Primary funding for the Colorado Learning Disabilities Research Center was provided by grant P50 HD27802 from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development. The content is solely the responsibility of the authors and does not necessarily reflect the official views of the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development or the National Institutes of Health. The authors were also supported by NIH grants R01 HD 47264, R01 HD 68728, R01 HD 59215, R01 HD 69728, R01 DC 05190, R01 HD38526, and R01 MH 70037 during the preparation of this report.

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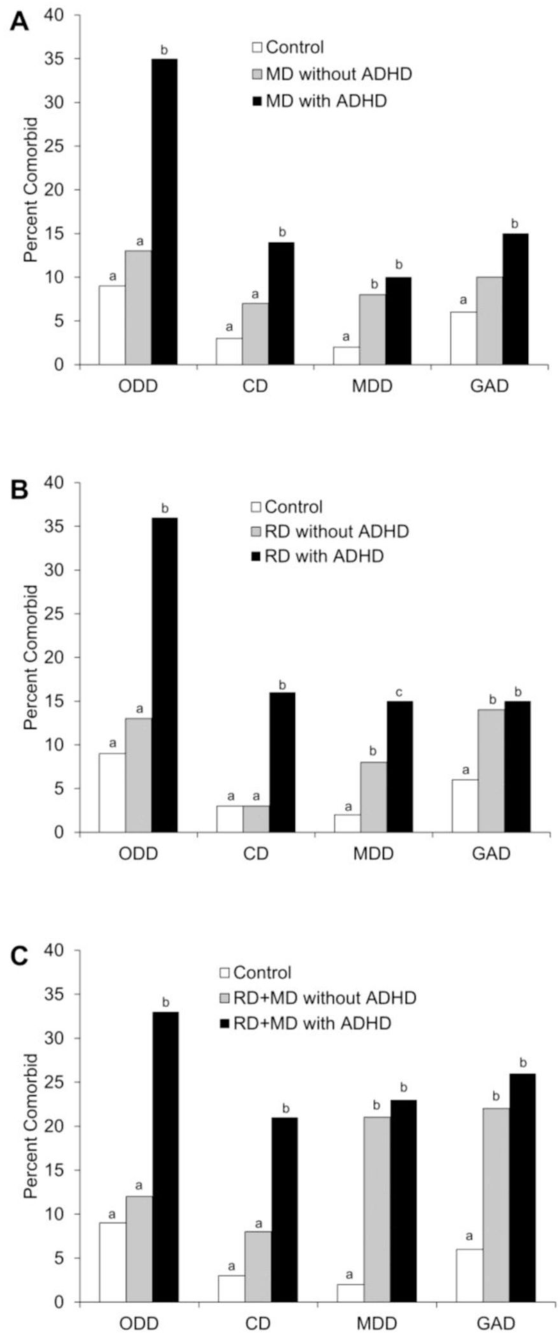

Figure 1.

Rates of MDD, GAD, ODD, and CD as a function of comorbid ADHD in groups with MD only (Panel A), RD only (Panel B), and RD + MD (Panel C). Different letters above the bars indicate a significant difference between groups (In panel A, the rate of GAD in the group with MD without ADHD was not significantly different from the rate in either of the other groups)

Table 1

Descriptive and diagnostic measures in groups with and without RD and MD

	Control M (SD)	RD only M (SD)	MD only M (SD)	RD + MD M (SD)
Descriptive characteristics				
Age	11.1 (2.2)$_a$	10.9 (2.1)$_a$	11.4 (2.4)$_a$	11.2 (2.3)$_a$
Maternal education (years)	15.3 (2.4)$_a$	14.0 (2.2)$_b$	13.7 (2.2)$_b$	13.4 (2.3)$_b$
Paternal education (years)	15.7 (2.5)$_a$	14.2 (2.6)$_b$	13.6 (2.3)$_c$	13.3 (2.5)$_c$
General Cognitive Ability				
Verbal IQ	112.6 (11.4)$_a$	99.2 (10.4)$_b$	95.6 (10.4)$_c$	91.3 (10.1)$_d$
Performance IQ	110.0 (11.8)$_a$	102.0 (10.1)$_b$	96.6 (11.8)$_c$	95.2 (12.1)$_c$
Full Scale IQ	111.4 (10.9)$_a$	100.4 (9.2)$_b$	96.1 (10.5)$_c$	93.5 (10.4)$_d$
Reading Achievement				
PIAT Reading Recognition	109.3 (8.7)$_a$	87.2 (6.5)$_b$	98.8 (7.7)$_c$	83.6 (8.0)$_d$
Time-limited Word Reading	0.69 (0.69)$_a$	−1.19 (0.40)$_b$	−0.08 (0.59)$_c$	−1.45 (0.50)$_d$
PIAT Reading Comprehension	110.8 (9.5)$_a$	92.7 (9.7)$_b$	99.0 (9.7)$_c$	86.9 (9.0)$_d$
Math Achievement				
WRAT Math	110.6 (11.1)$_a$	99.4 (8.7)$_b$	87.3 (8.5)$_c$	84.3 (8.9)$_d$
PIAT Math	105.5 (15.0)$_a$	94.7 (9.5)$_b$	80.7 (8.8)$_c$	77.5 (11.7)$_d$

Note: PIAT = Peabody Individual Achievement Test. WRAT = Wide Range Achievement Test. Ns: Control = 419, RD only = 241, MD only = 183, RD + MD = 188. Means with no common subscripts are significantly different (P < .01).

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Table 2

Comorbid psychopathology in groups with and without RD and MD

	Group comparisons				Multiple linear or logistic regression models		
	Control	**RD only**	**MD only**	**RD + MD**	**Reading**	**Math**	**Reading X Math**
Dimensional measures	M (SD)	M (SD)	M (SD)	M (SD)	*B* (SE)	*B* (SE)	*B* (SE)
DSM-IV Inattention	$1.26\ (2.13)_a$	$3.62\ (3.05)_b$	$3.27\ (3.12)_b$	$4.27\ (3.01)_c$	$.26\ (.04)^{**}$	$.25\ (.04)^{**}$	.05 (.03)
DSM-IV Hyperactivity-Impulsivity	$0.71\ (1.47)_a$	$2.07\ (2.59)_b$	$1.73\ (2.40)_b$	$1.92\ (2.30)_b$	$.16\ (.04)^{**}$	$.13\ (.04)^{**}$	.02 (.03)
ASEBA Internalizing	$-0.32\ (0.71)_a$	$0.15\ (1.02)_b$	$0.23\ (1.13)_b$	$0.60\ (1.46)_c$	$.17\ (.04)^{**}$	$.19\ (.04)^{**}$	$.09\ (.03)^{*}$
ASEBA Externalizing	$-0.34\ (0.77)_a$	$0.24\ (1.06)_b$	$0.16\ (1.05)_b$	$0.29\ (1.12)_b$	$.19\ (.04)^{**}$	$.12\ (.04)^{*}$	−.01 (.04)
Clinical Diagnoses	N (%)	N (%)	N (%)	N (%)			
Any DSM-IV ADHD subtype	$31\ (7\%)_a$	$76\ (32\%)_b$	$52\ (28\%)_b$	$70\ (37\%)_b$	$.52\ (.11)^{**}$	$.52\ (.11)^{**}$	−.04 (.09)
Inattentive Type	$20\ (5\%)_a$	$46\ (19\%)_b$	$32\ (18\%)_b$	$52\ (28\%)_c$	$.52\ (.13)^{**}$	$.49\ (.13)^{**}$	.00 (.10)
Hyp-Imp Type	$5\ (1\%)_a$	$6\ (3\%)_a$	$6\ (3\%)_a$	$3\ (1\%)_a$	.22 (.30)	.31 (.34)	−.35 (.34)
Combined Type	$6\ (1\%)_a$	$24\ (10\%)_b$	$14\ (8\%)_b$	$15\ (8\%)_b$	$.51\ (.20)^{*}$	$.39\ (.20)^{+}$	−.14 (.16)
Oppositional Defiant Disorder	$34\ (9\%)_a$	$47\ (21\%)_b$	$32\ (20\%)_b$	$34\ (21\%)_b$	$.23\ (.11)^{+}$	$.31\ (.12)^{*}$	−.13 (.11)
Conduct Disorder	$12\ (3\%)_a$	$17\ (8\%)_b$	$15\ (9\%)_b$	$22\ (13\%)_b$	$.23\ (.11)^{+}$	$.34\ (.14)^{*}$	−.12 (.13)
Depression	$9\ (2\%)_a$	$21\ (10\%)_b$	$12\ (7\%)_b$	$35\ (22\%)_c$	$.57\ (.18)^{**}$	$.54\ (.18)^{**}$	.08 (.14)
Generalized Anxiety Disorder	$23\ (6\%)_a$	$31\ (14\%)_b$	$18\ (11\%)_b$	$38\ (24\%)_c$	$.36\ (.13)^{*}$	$.25\ (.13)^{+}$	.13 (.10)

Note: ASEBA = Achenbach System of Empirically Based Assessment. ADHD = attention - deficit/hyperactivity disorder. Means or percentages with no common subscripts are significantly different (P < .01). Ns for measures of ADHD: Control = 419, RD only = 241, MD only = 183, RD + MD = 188. Ns for all other measures: Control = 375, RD only = 222, MD only = 163, RD + MD = 162.

$^{+}$ = P < .05,

* = P < .01,

** = P < .001

Table 3

Academic functioning and interventions in groups with and without RD and MD

	Group Comparisons				Multiple logistic regression analyses		
	Control N (%)	**RD only N (%)**	**MD only N (%)**	**RD + MD N (%)**	**Reading *B* (SE)**	**Math *B* (SE)**	**Reading X Math *B* (SE)**
Academic functioning							
Reading difficulty	55 (13%)$_a$	213 (88%)$_b$	90 (49%)$_c$	170 (90%)$_b$	2.24 (0.15)**	0.31 (0.12)*	0.24 (0.15)
Math difficulty	127 (30%)$_a$	116 (48%)$_b$	144 (79%)$_c$	153 (81%)$_c$	−0.05 (0.09)	1.25 (0.11)**	0.28 (0.09)*
English difficulty	71 (17%)$_a$	76 (32%)$_b$	42 (23%)$_c$	63 (34%)$_b$	0.28 (0.10)*	0.19 (0.10)$^{+}$	0.01 (0.09)
Like school	271 (65%)$_a$	110 (46%)$_b$	62 (34%)$_c$	70 (37%)$_c$	0.22 (0.08)*	0.36 (0.09)**	0.05 (0.06)
Dislike school	13 (3%)$_a$	22 (9%)$_b$	18 (10%)$_b$	21 (11%)$_b$	0.28 (0.14)*	0.27 (0.14)*	−0.03 (0.13)
Academic interventions							
Retained	3 (1%)$_a$	28 (12%)$_b$	13 (7%)$_b$	24 (13%)$_b$	1.42 (0.29)**	0.90 (0.32)**	−0.39 (0.27)
Extra help in math	6 (2%)$_a$	30 (23%)$_b$	36 (37%)$_c$	61 (61%)$_d$	0.95 (0.20)**	1.03 (0.21)**	0.06 (0.23)
Extra help in reading	7 (3%)$_a$	85 (64%)$_b$	22 (22%)$_c$	76 (76%)$_b$	2.21 (0.24)**	0.57 (0.20)*	−0.22 (0.25)
Any extra academic help	18 (7%)$_a$	97 (74%)$_b$	44 (45%)$_c$	86 (86%)$_d$	1.68 (0.17)**	0.41 (0.15)*	0.21 (0.17)

Notes. Percentages with no common subscripts are significantly different (P < .01). Sample size for measures of academic functioning and retention: Control = 419, RD only = 241, MD only = 183, RD + MD = 188. Sample size for measures of extra academic help: Control = 278, RD only = 152, MD only = 113, RD + MD = 115.

$^{+}$= P < .05,

*= P < .01,

**= P < .001

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Table 4

Global, academic, and social functioning in groups with and without RD and MD

	Group Comparisons				Multiple regression analyses		
	Control M (SD)	**RD only M (SD)**	**MD only M (SD)**	**RD + MD M (SD)**	**Reading *B* (SE)**	**Math *B* (SE)**	**Reading X Math *B* (SE)**
Global functioning							
Global Assessment Scale	92.3 (5.1)$_a$	84.1 (8.9)$_b$	83.2 (11.6)$_b$	77.5 (14.4)$_c$	.23 [.13, .33]**	.28 [.19, .37]**	.10 [.02, .18]+
Daily responsibilities	−0.42 (0.72)$_a$	0.32 (1.06)$_b$	0.24 (1.11)$_b$	0.55 (0.99)$_c$	.21 [.11, .31]**^	.26 [.16, .36]**	.09 [.03, .15]+
Academic functioning							
Grades	3.67 (0.48)$_a$	2.52 (0.79)$_b$	2.83 (0.93)$_c$	2.25 (0.95)$_d$	.41 [.27, .55]**	.20 [.06, .34]**	.11 [.01, .21]
Understanding assignments	−0.56 (0.51)$_a$	0.40 (1.01)$_b$	0.25 (1.02)$_b$	0.81 (1.12)$_c$	.36 [.26, .46]**	.26 [.16, .36]**	.15 [.09, .21]**
Overall Academic Problems	−0.53 (0.66)$_a$	0.63 (1.12)$_b$	0.27 (1.07)$_c$	0.78 (1.11)$_b$	.35 [.27, .43]**	.24 [.15, .33]**	.09 [.03, .15]
Social functioning							
ASEBA Social Problems	−0.34 (0.73)$_a$	0.35 (1.20)$_b$	0.19 (1.04)$_b$	0.45 (1.15)$_b$	.23 [.15, .31]**	.13 [.05, .21]**	.05 [−.02, .12]
CLDQ Social Isolation	−0.27 (0.66)$_a$	0.05 (1.09)$_b$	0.14 (1.02)$_b$	0.49 (1.31)$_c$	.10 [.00, .20]	.15 [.05, .25]*	.09 [.03, .15]*
Liked by peers	−0.27 (0.77)$_a$	0.00 (1.03)$_b$	0.29 (1.14)$_c$	0.56 (1.16)$_c$	.15 [−.01, .31]	.22 [.07, .37]*	.14 [.04, .24]*
Disliked by peers	−0.21 (0.68)$_a$	0.44 (1.53)$_b$	0.18 (1.20)$_b$	0.30 (1.38)$_b$	.24 [.08, .40]**^	.07 [−.08, .22]	.09 [−.03, .22]

ASEBA = Achenbach System of Empirically Based Assessment. CLDQ = Colorado Learning Difficulties Questionnaire. All scores are scaled so that higher scores indicate greater impairment. Means with no common subscripts are significantly different ($P < .01$). Sample size for liked or disliked by peers: Control = 278, RD only = 125, MD only = 102, RD + MD = 99.

^ indicates that the effect was no longer significant when ADHD symptoms were controlled ($P > .05$). No results changed when Full Scale IQ was covaried.

+ = < .05,

* = P < .01,

** = P < .001.

Table 5

Neuropsychological performance of groups with and without RD and MD

	Group Comparisons				Multiple regression analyses		
	Control M (SD)	RD only M (SD)	MD only M (SD)	RD + MD M (SD)	Reading *B* (SE)	Math *B* (SE)	Reading X Math *B* (SE)
Neuropsych. Composite	N = 419	N = 241	N = 182	N = 188			
Verbal Comprehension	−0.54 $(0.78)_a$	0.48 $(0.79)_b$	0.65 $(0.84)_b$	1.17 $(0.78)_c$	.33 [.27, .39]**	.47 [.41, .53]**	.02 [−.04, .08]
Phoneme Awareness	−0.52 $(0.61)_a$	0.80 $(0.87)_b$	0.22 $(0.82)_c$	1.39 $(1.06)_d$	.64 [.58, .70]**	.20 [.14, .26]**	.13 [.08, .18]**
Working Memory	−0.41 $(0.89)_a$	0.38 $(0.76)_b$	0.41 $(0.86)_b$	0.87 $(0.82)_c$	.28 [.22, .34]**	.36 [.30, .42]**	.03 [−.03, .09]
Naming Speed	−0.45 $(0.86)_a$	0.57 $(0.83)_b$	0.13 $(0.95)_c$	0.98 $(0.97)_d$	.47 [.41, .53]**	.18 [.12, .24]*	.06 [.00, .12]
Processing Speed	−0.50 $(0.85)_a$	0.42 $(0.84)_b$	0.49 $(0.86)_b$	0.97 $(0.92)_c$	.30 [.24, .36]**	.41 [.35, .47]**	.05 [−.01, .11]
	N = 340	N = 212	N = 149	N = 143			
Interference Control	−0.04 $(1.06)_a$	−0.27 $(0.95)_b$	0.36 $(0.94)_c$	−0.34 $(1.11)_b$	−.25 [−.35, −.15]**	.13 [.03, .23]*	.21 [.13, .29]**
Inhibition	−0.37 $(0.53)_a$	0.19 $(1.27)_b$	0.34 $(1.26)_b$	0.44 $(0.91)_b$	.16 [.06, .26]*	.23 [.13, .33]**	.04 [−.04, .12]
Set shifting	−0.30 $(0.65)_a$	0.02 $(1.02)_a$	0.34 $(0.96)_b$	0.52 $(1.31)_b$	−.03 [−.13, .07]	.39 [.29, .49]**	.12 [.04, .20]*
Vigilance	−0.41 $(0.74)_a$	0.15 $(1.00)_b$	0.29 $(0.99)_b$	0.66 $(1.07)_c$	.21 [.11, .31]**	.28 [.18, .38]$^{**\wedge}$	.09 [.01, .17]$^{+}$
Response Variability	−0.41 $(0.78)_a$	0.29 $(0.97)_b$	0.20 $(1.05)_b$	0.94 $(1.16)_c$	.28 [.18, .38]**	.23 [.13, .33]**	.10 [.02, .18]$^{+}$

All scores are scaled so that higher scores indicate greater impairment/poorer performance. Means with no common subscripts are significantly different (P < .01).

$^{\wedge}$indicates that the effect was no longer significant when IQ was controlled (P > .05). No results changed when ADHD symptoms were covaried.

$^{+}$= P < .05

*= P < .01,

**= P < .001.

Table 6

Linear regression models predicting reading or math simultaneously with all neuropsychological composites

Neuropsychological Composite	**Reading B (SE)**	**Math B (SE)**
Verbal Comprehension	.26 [.18, .34]**	.31 [.21, .41]**
Phoneme Awareness	.45 [.45, .55]**	.09 [−.01, .19]
Working Memory	.16 [.06, .26]**	.31 [.21, .41]**
Naming Speed	.12 [.03, .21]*	−.02 [−.12, .08]
Processing Speed	.17 [.09, .25]**	.25 [.15, .35]**
Interference Control	−.02 [−.08, .04]	−.06 [−.14, .02]
Response Inhibition	−.09 [−.19, .01]	.01 [−.11, .13]
Set shifting	−.08 [−.18, .02]	.12 [.04, .20]*
Vigilance	−.09 [−.19, .01]	.04 [−.06, .14]
Response variability	.09 [.01, .17]	.06 [−.02, .14]

Note: All measures are scaled so that positive *B* indicates that poorer performance on the neuropsychological measure is associated with lower math or reading achievement.

* = P < .01,

** = P < .001