**Colorado Learning Disabilities Research Center**

**Overview**

The Colorado Learning Disabilities Research Center (CLDRC; P50 HD27802) is a long-standing interdisciplinary, multisite research program that is supported by the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development. The CLDRC investigates the genetic and environmental etiologies, neurobiology, neuropsychology, classification, and outcomes of learning disabilities (LDs) and related disorders such as attention/deficit-hyperactivity disorder (ADHD). The overarching long-term goal of the CLDRC is to develop and refine a comprehensive neurodevelopmental and neurobiological model of LDs and related disorders, then to use that model to inform early screening and identification to guide prevention and treatment.

Until recently, theoretical models of LDs, ADHD, and related disorders typically implicated linear causal pathways in which a single genetic or environmental risk factor led to a specific neurocognitive dysfunction that was necessary and sufficient to explain the behavioral symptoms of the disorder. In addition to explicitly proposing that the neurobiological pathway to each disorder was relatively straightforward, these models also implicitly suggested that the causal pathways to different disorders were orthogonal. However, results from the past two decades of work in the CLDRC indicate that the overarching category of "learning disability" identifies a heterogeneous population that includes individuals with weaknesses in different aspects of reading, math, or writing, all of which may occur in the context of a wide range of general cognitive ability (e.g., Willcutt et al., 2019; Willcutt et al., 2013). Further, data from the CLDRC and other samples strongly suggest that LDs in (RD), math (MD), and writing (WD) co-occur much more often than expected by chance with one another (30 - 60%) and with other disorders such as ADHD (25-40%), and multivariate twin analyses suggest that the same genetic influences may increase risk for many of these difficulties (e.g., Hart, Petrill, Thompson, & Plomin, 2009; Knopik, Alarcon, & DeFries, 1997; Kovas, Harlaar, Petrill, & Plomin, 2005; R. K. Olson et al., 2013; Peterson et al., 2017; Trzesniewski, Moffitt, Caspi, Taylor, & Maughan, 2006; Wadsworth, DeFries, Willcutt, Pennington, & Olson, 2015; Willcutt, 2014; Willcutt, Betjemann, et al., 2010; Willcutt et al., 2019; Willcutt & Pennington, 2000; Willcutt, Pennington, & DeFries, 2000; Willcutt, Pennington, et al., 2010).

These shared genetic influences and the high rates of co-occurrence between putatively distinct LDs directly challenge single deficit models and the overall concept of specific learning disabilities. On the other hand, key results from the CLDRC and other related studies by our group also underscore the potential importance of the distinctions between different dimensions of LDs in reading, math, and writing.

**The current dataset**

The Colorado Learning Disabilities Research Center (CLDRC) twin study is an ongoing study of the etiology of learning and attentional difficulties that has included nearly 6,000 participants since the study was first initiated (e.g., DeFries et al., 1997; McGrath et al., 2011; R.K. Olson, Keenan, Byrne, & Samuelsson, 2017; Peterson et al., 2017; Willcutt, Pennington, et al., 2010). Papers describing the CLDRC twin study in detail are listed at the end of this document. The downloadable dataset includes the primary measures from 16 years of the study (2002 - 2017).

**The sample**

Recruitment procedures and exclusion criteria are described in detail in previous papers (e.g., Willcutt et al., 2019; Willcutt, Pennington, Olson, Chhabildas, & Hulslander, 2005; Willcutt et al., 2013), and are summarized more briefly here. In collaboration with 22 local school districts, parents of all twins between the ages of 8 and 18 were contacted and invited to complete the initial screening procedures for the study. After initial parental consent was obtained, two parallel recruitment procedures were conducted independently to identify twin pairs in which at least one of the twins exhibited elevations of learning or attentional difficulties, as well as a comparison sample of twin pairs in which neither twin exhibited either ADHD or reading difficulties. In addition, approximately 20% of families in the publicly available sample were recruited via the Colorado Twin Registry (Rhea, Gross, Haberstick, & Corley, 2006), a population-based registry of twins who are born in or move to the state and whose parents decline to opt-out of potential contact by researchers.

To identify twin pairs in which at least one twin exhibited significant reading difficulties, parental consent was requested to allow study staff to review each twin’s academic records, interview the parent, and obtain parent and teacher ratings of the twins' academic and attentional functioning. If either of the twins exhibited a significant history of learning or attentional difficulties during the screening, both members of the pair were invited to participate in the full study (90% of families identified by the screening procedure agreed to participate). Due to the primary focus of the overall study, pairs in which at least one twin exhibited significant learning difficulties were oversampled (approximately 60% of the final tested sample) to increase statistical power for analyses of extreme groups. 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.

**Exclusion criteria.** CLDRC staff conducted a telephone screening interview prior to any testing. Because the focus of the overall project is on the etiology and correlates of familial learning and attentional difficulties, potential participants with a documented brain injury, significant hearing or visual impairment, or other rare genetic or environmental etiology (e.g., Fragile X syndrome, Down syndrome or other sex chromosome anomalies) were excluded from the sample. In addition, any twins with a previous diagnosis of a pervasive developmental disorder, psychosis, tic disorder, or bipolar disorder were excluded from the study.

**Procedure**

As described in detail in previous papers, the twins completed a full day of testing at the University of Colorado Boulder, followed by a second day of testing at the University of Denver. All measures at both sites were administered by trained examiners who had previous experience working with children. All examiners were unaware of the diagnostic status of the child and the results of the testing conducted at the other sites. Parents of participants that were taking psychostimulant medication were asked to withhold medication for 24 hours prior to each session of the study to minimize the influence of medication on the results.

All procedures involving human subjects were reviewed and approved by the Institutional Review Boards at the University of Colorado Boulder and University of Denver. Parents gave their informed consent and children and adolescents assented to participate prior to their enrollment in the study. Prior to using these data all external investigators must complete their institution’s ethics webcourse for working with data from human subjects. All results should be reported in aggregate.

**Available Measures**

The remainder of this document describes the primary measures that are included in the dataset that is available for download. Most of the measures were completed by all participants, but some were added part of the way through the 16 years of the study, and are therefore available for a subset of participants. Measures that are available include:

* basic demographic information about the participants
  + age
  + grade
  + sex
* Standardized measures of academic achievement
  + reading
  + math
  + spelling
  + written expression
* measures of general cognitive ability and other aspects of cognition that are related to LDs
  + vocabulary
  + phonological processing
  + naming speed
  + processing speed

**Descriptive Information and Demographic Characteristics**

| **Table 1**  **Variable Descriptions: Descriptive and Demographic Information** | |
| --- | --- |
| **Variable(s)** | **Description / Comments** |
| **ID number** |  |
| PUBLICID | Unique ID for each individual for the publicly available dataset. |
| FamilyiD | Unique ID for each family: The two twins in a family will have the same FAMILYID. |
| INDID | Inidvidual ID: Twin 1 = 1 Twin 2 =2. |
| group | Family-level code indicating whether the pair was selected because at least one twin exhibited evidence of learning or attentional difficulties.  1 = history of learning or attentional difficulties in one or both of the twins in the pair  2 = no history of learning or attentional difficulties in either twin |
| READINGSCREEN  ADHDSCREEN | Individual-level code indicating whether screening procedures prior to testing indicated evidence of reading or attentional difficulties. 1 = potential case 2 = no prior evidence |
| RECRUIT Recruitment regime. 1 = twin registry, 2 = school | |
| **Demographic information** | |
| zyg | zygosity. 1 = MZ, 2 = DZ |
| SAMEOPPSEX | 1 = opposite sex twin pair, 2 = same sex twin pair |
| sex | 1 = male, 2 = female |
| age | age at time of IBG testing |
| GRADEYR | Grade year |

**Academic Achievement Measures**

Participants in the CLDRC completed an extensive battery of measures of academic achievement in reading, math, and written language. The text in this section describes each of these measures, and Table 2 provides the variable names and a description of the primary dependent measures that are included in the datafile.

**Reading**

The *Peabody Individual Achievement Test* (PIAT; Dunn & Markwardt, 1970) Reading Recognition subtest is an untimed measure of single-word reading (test-retest *r* = .94 - .98). Participants read up to 84 words one at a time on an easel that faces the participant. The datafile includes the standard score on this measure based on the normative sample for the test.

The *Time-Limited Word Reading* *Measure* (Olson, Wise, Conners, Rack, & Fulker, 1989) assesses fluent word recognition ability by imposing a two second time limit on subjects' voice-onset for each word. A short list of 14 words is presented on a computer to all subjects. The subjects read each word aloud as soon as they have recognized it. They are instructed to go as quickly as they can without making errors. The pronunciation of these words is scored online by the experimenter for accuracy and audio recorded for later error analysis. The performance on the 14-item screener list is used to determine initial placement into a difficulty-scaled list of 182 words. Presentation of words continues until the subject makes 10 errors out of the last 20 words or until the end of the list is reached. The primary dependent measure is the position in the list at which the subject dropped out. The variable in the datafile is that final score age-corrected and standardized against the control sample.

The *Test of Word Reading Efficiency Sight Word Efficiency* subtest (TOWRE; Torgesen, Wagner, & Rashotte, 1999) requires the participant to read as many single words as possible in 45 seconds (test-retest *r* = .84 - .97). The datafile includes the standard score on this measure.

On the *Woodcock-Johnson Tests of Achievement, Third Edition (WJ-III) Reading Fluency* subtest, participants read simple sentences and indicate their veracity by circling “Y” or “N” on the response sheet (test-retest *r* = .80-.94; McGrew & Woodcock, 2001). The dependent measure is the number of correct responses in three minutes. The datafile includes the standard score on this measure.

The *PIAT Comprehension* subtest (Dunn & Markwardt, 1970) requires participants to read silently short one- or two-sentence passages. The participant then turns the page and selects one of four pictures that best depicts the meaning of the passage without referring back to the text (median test‑retest reliability = .90).

**Spelling**

The *PIAT Spelling* subtest provides a measure of spelling recognition. Participants choose the correct spelling of a word from four potential options (Dunn & Markwardt, 1970). The *Wide Range Achievement Test-Revised* (WRAT-R) Spelling subtest is a measure of spelling production (Jastak & Wilkinson, 1984). The participant writes down the correct spelling of up to 45 items presented orally by the examiner; the test is discontinued after 10 consecutive spelling errors. The published alternate form reliability is .90. The datafile includes the standard scores for each spelling measure.

Participants completed two orthographic coding measures that required the recognition of the correct spelling of a target word with phonologically similar foils. In the *Word-Pseudohomophone Choice* task, participants select the real word from a real word paired with a nonword that would have the same pronunciation (Which is the real word? rain rane). In the *Homophone Choice* task, participants choose which word in a homophone pair answers a simple question (Which means to look at? see sea). Stimuli in both tasks are presented via computer and participants indicate their choice by pressing a button (Olson, Forsberg, Wise, & Rack, 1994). The dependent measure for each task is percent correct, and the variable provided in the datafile is a composite of the two scores, each age-corrected and standardized against our control sample.

**Math**

Most participants completed two standardized measures of math achievement.On the *PIAT Math* subtest a series of problems are presented orally, and the participant then selects among four potential responses (Dunn & Markwardt, 1970). The majority of the specific items on the PIAT assess understanding and application of math concepts, and a smaller percentage of items measure math computation abilities (split-half reliability for the total score = .90 - .96). In contrast, all items on the Math subtest of the *Wide Range Achievement Test, Revised* (WRAT-R; Jastak & Wilkinson, 1984) involve paper-and-pencil calculations (reliability = .92). A subset of participants were also administered two math subtests from the WJ-III battery (McGrew & Woodcock, 2001). In *WJ-III Applied Problems*, the examiner reads story problems while the participant follows along and then responds (split-half reliability = .93). In *WJ-III Math Fluency*, the participant is given several sheets of simple math calculations and the score is the number of correct responses in three minutes (test-retest reliability = .89-.95). The datafile includes the standard scores for each math measure.

**Written language**

Stimuli on the *WJ‑III Writing Fluency subtest* include three target words and a simple line drawing, and the participant is told to use all three words in a complete grammatical sentence that describes the picture. The primary dependent measure is the number of sentences that are completed correctly in 7 minutes (median test‑retest reliability = .90 in the age range of our sample; McGrew & Woodcock, 2001). The datafile includes the standard score for Writing Fluency.

*WJ‑III* *Writing Samples* is an untimed test that requires participants to write a single sentence in response to the tester’s oral directions and a pictorial prompt. Two independent raters assigned 0 to 2 points to each response based on the scoring key in the WJ‑III manual. The two raters’ scores for each item are then averaged and summed across items to create the total raw score and corresponding standard score based on the WJ-III normative sample (test‑retest reliability = .83 - .87; McGrew & Woodcock, 2001). The datafile includes the standard score for Writing Samples.

|  |  |
| --- | --- |
| **Table 2**  **Variable Descriptions: Academic Achievement Measures** | |
| **Variable(s)** | **Description / Comments** |
| **Reading** |  |
| pIAtrecss | PIAT Reading Recognition scaled score (Mean = 100, SD = 15). |
| zTLWORDREC | Time -limited Word Recognition score age-corrected and standardized against the control sample. |
| towrewrdss | TOWRE Sight Word Effieciency scaled score (Mean = 100, SD = 15). |
| pIAtcompss | PIAT Comprehension scaled score (Mean = 100, SD = 15) |
| WJ3READFLSS | WJIII Reading Fluency scaled score (Mean = 100, SD = 15) |
| **Spelling** |  |
| piAtspelLss | PIAT Spelling scaled score (Mean = 100, SD = 15) |
| wratSPELLss | WRAT Spelling scaled score (Mean = 100, SD = 15) |
| ZORTH | Orthographic Coding Composite of Word-Pseudohomophone Choice and Homophone Choice. Age-corrected and standardized against the control sample. |
| **Math (Math measures were administered in years 1-5 and 11 - 15)** | |
| pIAtmathss | PIAT Math standard score (Mean = 100, SD = 15) |
| wrATmathss | WRAT Math standard score (Mean = 100, SD = 15) |
| WJ3APSS | WJ-III Applied Problems scaled score (Mean = 100, SD = 15) |
| WJ3MATHFLSS | WJ-III Math Fluency scaled score (Mean = 100, SD = 15) |
| **WRITING (Writing measures were administered in years 6 - 15)** | |
| wj3sampss | WJ-III Writing Samples scaled score (Mean = 100, SD = 15) |
| WJ3WRITEFLSS | WJ-III Writing Fluency scaled score (Mean = 100, SD = 15) |

**Cognitive Measures**

In addition to the primary measures of academic achievement and ADHD symptoms, participants also completed measures of general cognitive ability, language skills related to reading, and processing and naming speed. The text in this section describes each of these measures, and Tables 3 and 4 provides the variable names and a description of the primary dependent measure for each cognitive task.

**Intelligence**

In years 1 - 5 each participant completed the full Wechsler Intelligence Scale for Children, Revised (WISC\_R, ages 8 – 16; Wechsler, 1974) or Wechsler Adult Intelligence Scale, Revised (WAIS-R, ages 17 and 18; Wechsler, 1981). The Wechsler test versions were then updated to the WISC-III (Wechsler, 1991) and WAIS-III (Wechsler, 1997) for years 6 - 10, and all participants completed the full WISC-III or WAIS-III during this period. Beginning in year 11 a subset of the WISC-III and WAIS-III subtests were dropped due to time constraints. Short form IQ scores were calculated for the measures of Verbal IQ (Vocabulary and Information), Performance IQ (Block Design and Object Assembly), and Full Scale IQ.

The WETEST variable identifies which version of the Wechsler Intelligence Test was completed by the participant (1 = full WISC-R, 2= full WAIS-R, 3 = full WISC-III, 4 = full WAIS-III, 5 = short form WISC-III, 6 = short form WAIS-III). Standardized scores are based on the normative sample for each measure; to the extent standardizations may vary across versions, additional consideration may be needed.

| **Table 3**  **Variable Descriptions: Intelligence** | |
| --- | --- |
| **Variable(s)** | **Description / Comments** |
| **Wechsler Subtest scores** (Note: For all subtest scores range = 1-19, mean = 10, SD = 3) | |
| weiss | Information |
| wesss | Similarities (Discontinued in year 16 due to time constraints) |
| weass | Arithmetic |
| wevss | Vocabulary |
| wecss | Comprehension (Discontinued in year 16 due to time constraints) |
| wepcss | Picture Completion (Discontinued in year 16 due to time constraints) |
| wepass | Picture Arrangement (Discontinued in year 16 due to time constraints) |
| webdss | Block Design |
| weoass | Object Assembly |
| wecbdss | WISC Coding or WAIS Digit Symbol |
| wedsf | Digit Span digits forward raw score (Total items correct) |
| wedsb | Digit Span digits backward raw score (Total items correct) |
| wedsss | Wechsler digit span total scaled score (1-19) |
| **IQ summary scores** (Note: For all IQ summary scores M = 100, SD = 15) | |
| weviqc | Verbal IQ based on all subtests in years 1 - 15 and short form (Vocabulary and Information) in years 16 - 20. |
| wepiqc | Performance IQ based on all subtests in years 1 - 15 and short form (Block Design and Object Assembly) in years 16 - 20. |
| wefsiqc | Full Scale IQ based on all subtests in years 1 - 15 and short form (Block Design, Object Assembly, Vocabulary and Information) in years 16 - 20. |
| weviq | Verbal IQ for cases with all subtests (missing for years 16 - 20) |
| weviqsf | Verbal IQ based on short form for all participants (Vocabulary and Information) |
| wepiq | Performance IQ for cases with all subtests (missing for years 16 - 20) |
| wepiqsf | Performance IQ based on short form for all participants (Block Design and Object Assembly) |
| wefsiq | Full Scale IQ for cases with all subtests (missing for years 16 - 20) |
| wefsiqsf | Full Scale IQ based on 4-subtest short form for all cases |

**Phoneme Awareness**

Participants completed two phoneme awareness measures that required the segmentation and manipulation of phonemes, skills in which numerous studies have found children with reading disabilities to be deficient. The *Phoneme Segmentation and Transposition test* requires the participant to transform words into their Pig-Latin equivalent (R. K. Olson, Forsberg, Wise, & Rack, 1994). The participant is told the rules for transforming the words (e.g., move the initial phoneme to the end of the word, and add the long a sound), and completes nine practice words read by the examiner. The test trials then require the participant to transform words read by the examiner into their equivalent in Pig-Latin. The primary dependent variable is a weighted percent correct on the 45 test items, such that participants receive the maximum score for following the first-phoneme rule described in the instructions (e.g., read-thay for thread), but also receive partial credit if they follow a first-letter (hread-tay) or onset (ead-thray) strategy.

The *Phoneme Deletion* task (Olson et al., 1994) is based on the Bruce (1964) phoneme-deletion task and the Rosner and Simon (1971) auditory-analysis task (Bruce, 1964; Rosner & Simon, 1971). On each of the 40 trials, participants hear a pronouncable nonword, which they are asked to repeat (e.g., say ‘plig’). They are then asked to say the nonword again after removing a specified phoneme (e.g., say ‘plig’ without the ‘l’). If done correctly, the result is a word (e.g., after dropping the ‘l’, ‘plig’ becomes ‘pig’). The primary dependent variable is the percent of correct trials. The variable provided in the datafile is a composite of the Phoneme Segmentation and Transposition and Phoneme Deletion scores, each age-corrected and standardized against our control sample.

**Phonological Decoding**

The *Oral Nonword Reading task* (Olson et al., 1994) requires the participant to read aloud 45 one-syllable and 40 two-syllable nonwords. The nonwords are presented on the computer one at a time, and responses are recorded for subsequent analyses of errors. The dependent variable is the percent of responses that are phonetically reasonable.

The *TOWRE Phonetic Decoding Efficiency* subtest (Torgesen, Wagner, & Rashotte, 1999) requires the participant to read as many nonwords as possible in 45 seconds (test-retest r = .89). The datafile includes the standard score on this measure.

**Vocabulary**

The *Peabody Picture Vocabulary Test* (PPVT-III; Dunn & Dunn, 1997) is a test of receptive vocabulary in which participants select one of four line drawings to best match the meaning of each word uttered by the tester. There are 204 words of increasing difficulty, but only items within an individuals critical range (basal to ceiling) are administered. The raw score is the number correct below the ceiling. Published test-retest reliability is .92. The datafile includes the standard score.

**Processing and Naming Speed**

**Processing Speed.** The *Wechsler Symbol Search* (Wechsler, 1991) and WISC *Coding and WAIS Digit Symbol* 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 *Identical**PicturesTest*(French, Ekstrom, & Price, 1963) requires the participant to identify as quickly as possible the one picture out of five options that matches a target picture. The datafile includes the scaled score for Symbol Search and Coding / Digit Symbol, and age-corrected and standardized scores for the Identical Pictures and Colorado Perceptual Speed tasks.

**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 score is the number of correct responses minus the number of incorrect responses. The datafile includes this score for each of the four trials, age-corrected and standardized against the control sample.The datafile includes the raw number correct and incorrect for each of the four trials.

|  |  |
| --- | --- |
| **Table 4**  **Variable Descriptions: Cognitive Tasks** | |
| **Variable(s)** | **Description / Comments** |
| **Phonological processing / non-word reading** | |
| znonPC | Laboratory measure of oral nonword reading, age-corrected and standardized against the control sample. |
| TOWRENONSS | TOWRE Phonetic Decoding scaled score (Mean = 100, SD = 15) |
| ZPA | Phoneme awareness composite score based on Pig Latin and Phoneme Deletion tasks. Age-corrected and standardized against the control sample. |
| **Vocabulary** | |
| PPVTSS | Peabody Picture Vocabulary Test-III scaled score (Mean = 100, SD = 15) |
| **Processing Speed** |
| WESEARCHSS | Wechsler Symbol Search scaled score (Mean = 10, SD = 3) |
| wecbdss | WISC Coding or WAIS Digit Symbol (Mean = 10, SD = 3) |
| ZIDENPICS | Identical Pictures Test score, age-corrected and standardized against the control sample. |
| zcpstot | Colorado Perceptual Speed score, age-corrected and standardized against the control sample. |
| **Naming Speed** |  |
| Zrannum | Rapid Automatized Naming numbers score, age-corrected and standardized against the control sample |
| Zrancol | Rapid Automatized Naming colors score, age-corrected and standardized against the control sample |
| Zranpic | Rapid Automatized Naming picturesscore, age-corrected and standardized against the control sample |
| Zranlet | Rapid Automatized Naming letters score, age-corrected and standardized against the control sample |

**ADHD Measures**

In addition to a primary focus on learning difficulties, the CLDRC has also investigated the etiology of the frequent comorbidity between learning difficulties and symptoms of attention-deficit/hyperactivity disorder (ADHD). Parents and teachers rated ADHD symptoms in each twin on the *Disruptive Behavior Rating Scale* (DBRS; Barkley & Murphy, 1998), a widely-used rating scale that asks the respondent to indicate on a four point scale (*never or rarely*, *sometimes*, *often*, and *very often*) the frequency that the child exhibits each of the nine DSM‑IV inattention symptoms and nine DSM‑IV hyperactivity‑impulsivity symptoms. Items that were rated 2 or 3 (e.g., "often" or "very often") were coded as positive symptoms for analyses that required symptom counts or identification of participants with and without ADHD. The downloadable dataset includes three types of measures of ADHD measures (Table 5).

**Dimensional measures of severity of ADHD behaviors:** The total score on the 9 inattention or hyperactivity-impulsivity items provide a dimensional measure of ADHD behaviors. These variables are provided separately for parent ratings (PINTOT and PHYPTOT) and teacher ratings (TINTOT and THYPTOT).

**DSM-IV ADHD symptom counts.** These variables provide the total number of symptoms of inattention and hyperactivity-impulsivity endorsed by parents and teachers (PINSX, PHYPSX, TINSX, THYPSX). In addition, parent and teacher ratings were also combined using the "or rule" algorithm from the DSM‑IV field trials to create overall inattention and hyperactivity‑impulsivity symptom counts across parent and teacher ratings (ORINSX and ORHYPSX). This algorithm codes a symptom as positive if it is endorsed by either rater (Lahey et al., 1994).

**DSM-IV ADHD subtypes.** Participants met symptom criteria for DSM-IV ADHD if they exhibited six or more symptoms of inattention or six or more symptoms of hyperactivity-impulsivity. Individuals who exhibited six or more symptoms of both inattention and hyperactivity‑impulsivity were classified as DSM‑IV Combined Type (ADHD-C). 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).

|  |  |
| --- | --- |
| **Table 5**  **Variable Descriptions: ADHD Measures** | |
| **Variable(s)** | **Description / Comments** |
| **DSM-IV ADHD Total Scores** | |
| pinTOT | parent report total score on inattention items (Range = 0 - 27) |
| phypTOT | parent report total score on hyperactivity-impulsivity items (Range = 0 - 27) |
| tinTOT | teacher report total score on inattention items (Range = 0 - 27) |
| thypTOT | teacher report total score on hyperactivity-impulsivity items (Range = 0 - 27) |
| **DSM-IV ADHD Symptom counts** | |
| pinsx | parent report DSM-IV inattention symptoms (Range 0 - 9) |
| phypsx | parent report DSM-IV hyp-imp symptoms (Range 0 - 9) |
| tinsx | teacher report DSM-IV inattention symptoms (Range 0 - 9) |
| thypsx | teacher report DSM-IV hyp-imp symptoms (Range 0 - 9) |
| orinsx | or rule DSM-IV inattention symptoms (Range 0 - 9) |
| orhypsx | or rule DSM-IV hyp-imp symptoms (Range 0 - 9) |
| **DSM-IV ADHD subtypes (0 = not ADHD, 1 = inattentive type, 2 = hyp-imp type, 3 = combined type** | |
| PDSM4 | parent report DSM-IV ADHD subtype |
| TDSM4 | teacher report DSM-IV ADHD subtype |
| ORDSM4 | or rule DSM-IV ADHD subtype (Combined parent and teacher ratings) |

**Citations that describe the CLDRC and the specific measures in the dataset**

McGrath, L. M., Pennington, B. F., Shanahan, M. A., Santerre-Lemmon, L. E., Barnard, H. D., Willcutt, E. G., . . . Olson, R. K. (2011). A multiple deficit model of reading disability and attention-deficit/hyperactivity disorder: Searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry, 52*, 547-557.

Olson, R. K., Hulslander, J., Christopher, M., Keenan, J. M., Wadsworth, S. J., Willcutt, E. G., . . . DeFries, J. C. (2013). Genetic and environmental influences on writing and their relations to language and reading. *Annals of Dyslexia*.

Willcutt, E. G., Betjemann, R. S., McGrath, L. M., Chhabildas, N. A., Olson, R. K., DeFries, J. C., & Pennington, B. F. (2010). Etiology and neuropsychology of comorbidity between RD and ADHD: The case for multiple-deficit models. *Cortex, 46*, 1345-1361.

Willcutt, E. G., Pennington, B. F., Duncan, L., Smith, S. D., Keenan, J. M., Wadsworth, S. J., & DeFries, J. C. (2010). Understanding the complex etiology of developmental disorders: Behavioral and molecular genetic approaches. *Journal of Developmental and Behavioral Pediatrics, 31*, 533-544.

Willcutt, E. G., Pennington, B. F., Olson, R. K., Chhabildas, N., & Hulslander, J. (2005). Neuropsychological analyses of comorbidity between reading disability and attention deficit hyperactivity disorder: In search of the common deficit. *Developmental Neuropsychology, 27*, 35-78.

Willcutt, E. G., Petrill, S. A., Wu, S., Boada, R., DeFries, J. C., Olson, R. K., & Pennington, B. F. (2013). Implications of comorbidity between reading and math disability: Neuropsychological and functional impairment. *Journal of Learning Disabilities, 46*, 500-516.

Willcutt, E. G., McGrath, L. M., Pennington, B. F., Keenan, J. M., DeFries, J. C., Olson, R. K., & Wadsworth, S. J. (2019). Understanding comorbidity between specific learning disabilities. *New Directions in Child and Adolescent Development, 165*, 91-109.

**All references cited in this document**

Barkley, R. A., & Murphy, K. (1998). *Attention-deficit hyperactivity disorder: A clinical workbook* (Vol. 2nd). New York, NY: Guilford Press.

Bruce, D. J. (1964). The analysis of word sounds by young children. *British Journal of Psychology, 34*, 158-170.

DeFries, J. C., Filipek, P. A., Fulker, D. W., Olson, R. K., Pennington, B. F., Smith, S. D., & Wise, B. W. (1997). Colorado Learning Disabilities Research Center. *Learning Disabilities: A Multidisciplinary Journal, 8*, 7-19.

DeFries, J. C., Singer, S. M., Foch, T. T., & Lewitter, F. I. (1978). Familial nature of reading disability. *British Journal of Psychiatry, 132*, 361-367.

Denckla, M. B., & Rudel, R. G. (1976). Rapid "automatized" naming (R.A.N): dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14*, 471-479.

Dunn, L.M., & Dunn, M. (1997). *Peabody Picture Vocabulary Test, Third Edition* Circle Pines, MN: American Guidance Service.

Dunn, L. M., & Markwardt, F. C. (1970). *Examiner's Manual: Peabody Individual Achievement Test*. Circle Pines, MN: American Guidance Service.

French, J. W., Ekstrom, R. G., & Price, L. A. (1963). *Manual for a kit of reference tests for cognitive factors*. Princeton, NJ: Educational Testing Service.

Hart, S. A., Petrill, S. A., Thompson, L. A., & Plomin, R. (2009). The ABCs of Math: A genetic analysis of mathematics and its links with reading ability and general cognitive ability. *Journal of Educational Psychology, 101*, 388-402.

Jastak, S., & Wilkinson, G. S. (1984). *Wide Range Achievement Test, Revised: Administration Manual*. Wilmington, DE.

Knopik, V. S., Alarcon, M., & DeFries, J. C. (1997). Comorbidity of mathematics and reading deficits: evidence for a genetic etiology. *Behavior Genetics, 27*, 447-453.

Kovas, Y., Harlaar, N., Petrill, S. A., & Plomin, R. (2005). 'Generalist genes' and mathematics in 7-year-old twins. *Intelligence, 33*, 473-489.

Lahey, B. B., Applegate, B., McBurnett, K., Biederman, J., Greenhill, L., Hynd, G. W., . . . Richters, J. (1994). DSM-IV field trials for attention deficit hyperactivity disorder in children and adolescents. *American Journal of Psychiatry, 151*, 1673-1685.

McGrath, L. M., Pennington, B. F., Shanahan, M. A., Santerre-Lemmon, L. E., Barnard, H. D., Willcutt, E. G., . . . Olson, R. K. (2011). A multiple deficit model of reading disability and attention-deficit/hyperactivity disorder: Searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry, 52*, 547-557.

McGrew, K. S., & Woodcock, R. W. (2001). *Technical Manual: Woodcock-Johnson III*. Itasca,IL: Riverside Publishing.

Olson, R. K., Forsberg, H., Wise, B., & Rack, J. (1994). Measurement of word recognition, orthographic, and phonological skills. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement issues* (pp. 243-277). Baltimore, MD: Paul H. Brookes Publishing Company.

Olson, R. K., Hulslander, J., Christopher, M., Keenan, J. M., Wadsworth, S. J., Willcutt, E. G., . . . DeFries, J. C. (2013). Genetic and environmental influences on writing and their relations to language and reading. *Annals of Dyslexia*.

Olson, R. K., Keenan, J. M., Byrne, B., & Samuelsson, S. (2017). Genetic and environmental influences on the development of reading and related skills. In K. Cain, D. Compton & R. Parilla (Eds.), *Theories of Reading Development* (pp. 33-53): John Benjamins Publishing Co.

Olson, R. K., Wise, B., Conners, F., Rack, J., & Fulker, D. W. (1989). Specific deficits in component reading and language skills: Genetic and environmental influences. *Journal of Learning Disabilities, 22*, 339-348.

Peterson, R. L., Boada, R., McGrath, L., Willcutt, E. G., Olson, R. K., & Pennington, B. F. (2017). Cognitive prediction of reading, math, and attention: Shared and unique influences. *Journal of Learning Disabilities, 50*, 408-421.

Rhea, S.A., Gross, A.A., Haberstick, B.C.,& Corley, R. P. (2006). Colorado Twin Registry.*Twin Research and Human Genetics*, 9(6), 941-9.

Rosner, J., & Simon, D. (1971). The Auditory Analysis Test: An initial report. *Journal of Learning Disabilities, 4*, 384-392.

Torgesen, J., Wagner, R., & Rashotte, C. A. (1999). *A Test of Word Reading Efficiency (TOWRE)*. Austin,TX: Pro-Ed.

Trzesniewski, K. H., Moffitt, T. E., Caspi, A., Taylor, A., & Maughan, B. (2006). Revisiting the association between reading achievement and antisocial behavior: new evidence of an environmental explanation from a twin study. *Child Development, 77*, 72-88.

Wadsworth, S. J., DeFries, J. C., Willcutt, E. G., Pennington, B. F., & Olson, R. K. (2015). The Colorado longitudinal twin study of reading difficulties and ADHD: Etiologies of comorbidity and stability. *Journal of Twin Research and Human Genetics, 18*, 755-761.

Wechsler, D. (1974). *Manual for the Wechsler Intelligence Scale for Children, Revised*. New York, NY: The Psychological Corportaiton.

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale, Revised.* New York, NY: The Psychological Corportaiton.

Wechsler, D. (1991). *Manual for the Wechsler Intelligence Scale for Children, Third Edition*. San Antonio,TX: The Psychological Corporation.

Wechsler, D. (1997). *WAIS-III administration and scoring manual.* San Antonio, TX: The Psychological Corporation.

Willcutt, E. G. (2014). Using behavior genetic methods to understand the etiology of comorbidity. In S. Rhee & A. Ronald (Eds.), *Behavior Genetics of Psychopathology* (pp. 231-252). New York: Springer.

Willcutt, E. G., Betjemann, R. S., McGrath, L. M., Chhabildas, N. A., Olson, R. K., DeFries, J. C., & Pennington, B. F. (2010). Etiology and neuropsychology of comorbidity between RD and ADHD: The case for multiple-deficit models. *Cortex, 46*, 1345-1361.

Willcutt, E. G., McGrath, L. M., Pennington, B. F., Keenan, J. M., DeFries, J. C., Olson, R. K., & Wadsworth, S. J. (2019). Understanding comorbidity between specific learning disabilities. *New Directions in Child and Adolescent Development, 165*, 91-109.

Willcutt, E. G., & Pennington, B. F. (2000). Psychiatric comorbidity in children and adolescents with reading disability. *Journal of Child Psychology and Psychiatry, 41*, 1039-1048.

Willcutt, E. G., Pennington, B. F., & DeFries, J. C. (2000). Twin study of the etiology of comorbidity between reading disability and attention-deficit/hyperactivity disorder. *American Journal of Medical Genetics Part B (Neuropsychiatric Genetics), 96*, 293-301.

Willcutt, E. G., Pennington, B. F., Duncan, L., Smith, S. D., Keenan, J. M., Wadsworth, S. J., & DeFries, J. C. (2010). Understanding the complex etiology of developmental disorders: Behavioral and molecular genetic approaches. *Journal of Developmental and Behavioral Pediatrics, 31*, 533-544.

Willcutt, E. G., Pennington, B. F., Olson, R. K., Chhabildas, N., & Hulslander, J. (2005). Neuropsychological analyses of comorbidity between reading disability and attention deficit hyperactivity disorder: In search of the common deficit. *Developmental Neuropsychology, 27*, 35-78.

Willcutt, E. G., Petrill, S. A., Wu, S., Boada, R., DeFries, J. C., Olson, R. K., & Pennington, B. F. (2013). Implications of comorbidity between reading and math disability: Neuropsychological and functional impairment. *Journal of Learning Disabilities, 46*, 500-516.