

Developmental Delay & ADHD

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Developmental Delays in Children with ADHD

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Abstract

ADHD is often co-morbid with other disorders, but it is often assumed that academic, language, or motor skills problems are secondary to ADHD rather than that attention problems are secondary to the other disorder or both disorders have a shared etiology. We assessed for co-morbid developmental disorders and which cognitive processes were impaired in children with ADHD. Measures of intelligence, language, motor skills, social cognition, and executive functions were administered to children with ADHD (n=53) and age/sex-matched typical children. Clinically significant deficits were two to seven times as common in children with ADHD as in typical children, and the structure of ability differed in the two groups. Abilities were less differentiated in children with ADHD. The results indicate a need for comprehensive screening for developmental disorders in children with ADHD and imply that research needs to focus on how ADHD and developmental disorders may share an etiology.

There is a growing consensus that Attention Deficit Hyperactivity Disorder (ADHD) cannot be explained by a single core neuropsychological deficit (Pennington, 2005) and a case has been made for identifying how competing theories of ADHD (e.g., the executive dysfunction and motivational models) may interact to cause the disorder (Sonuga-Barke, 2005). The idea that there are multiple pathways to ADHD is attractive given the heterogeneity of ADHD samples, but simply focusing on interactions between putative ADHD-specific mechanisms may not be sufficient. The problem is that not only is ADHD often co-morbid with other behavioural syndromes (Bauermeister, Shrout, Ramirez, Bravo, Alegria et al., 2007), it is also often co-morbid with Learning Disorders (Shaywitz & Shaywitz, 1991), Communication Disorders (Kovac, Garabedian, Du Souich, & Palmour, 2001) and Motor Skills Disorder (Rasmussen & Gillberg, 2000). If DSM-IV permitted the diagnosis of ADHD in children with pervasive developmental disorders, ADHD would also be commonly co-morbid with these disorders (Goldstein & Schwabach, 2004).

The possibility that co-morbid conditions play a role in causing inattention or hyperactivity/impulsivity is often discounted. Willcutt, Doyle, Nigg, Faraone and Pennington (2005, p. 1342), citing Barkley (1997), suggested the opposite, that “ADHD symptoms and [executive functioning] impairments or other neurocognitive weaknesses may directly cause poor performance on standardised tests of intelligence or academic achievement.” Pliszka, Bernet, Bukstein and Walter (2007, p. 901) suggested that when academic problems are evident, “it is more appropriate to treat the ADHD and then determine whether the academic problems begin to resolve as the patient is more attentive in learning situations.” They recommended that if a child’s learning problems did not resolve, “the patient’s ADHD be optimally treated before ...

testing” to assess whether the child has intellectual, academic, language, or other neuropsychological deficits. Because deficits associated with specific developmental disorders are not regarded as affecting attention, hyperactivity or impulsivity, “neuropsychological testing, speech-language assessments, and computerised testing of attention or inhibitory control are not required as part of a routine assessment for ADHD” (Pliszka et al., 2007, p. 901).

It is easy to understand how ADHD may affect performance on intelligence, language, and other tests, but it is puzzling that there is little recognition of how poor intellectual, language, or other abilities might affect attention, activity level, and impulsiveness. Put simply, people of lower intellect may be more likely “to make careless mistakes in schoolwork,” “not follow through on instructions,” “fail to finish schoolwork,” have “difficulty organising tasks and activities,” be “reluctant to engage in tasks that require sustained mental effort,” or be “forgetful in daily activities” (American Psychiatric Association, 2000, p. 92). Are these symptoms of ADHD, or are they exactly what is to be expected of children who consistently have difficulty understanding what is being asked of them due to intellectual or language problems?

Why has this association between ability deficits and ADHD symptoms been discounted previously? One possible explanation is that previous research on ADHD prevalence and co-morbidity has given priority to assessing oppositional, anxiety, mood, and substance use disorders rather than developmental disorders. For example, August, Realmutto, MacDonald, Nugent and Crosby (2001) excluded children with an IQ less than 80 or a pervasive developmental disorder. Although they assessed children’s intelligence and academic skills, they didn’t consider whether children met criteria for a Learning Disorder even though spelling and arithmetic scores were

significantly less than 100. Bauermeister et al. (2007) obtained reports on children's school, speech, and language problems, but did not directly assess any of these.

Most knowledge about co-morbidity between ADHD and other developmental disorders is based on small clinical studies. These studies focused on co-morbidity between subsets of two or three disorders, such as ADHD and Reading Disorder (Ho, Chan, Leung, Lee, & Tsang, 2005), ADHD and Communication Disorder (Kovac et al., 2001), ADHD and motor skills disorder (Piek, Pitcher & Hay, 1999; Pitcher, Piek & Hay, 2003), or ADHD, Reading Disorder and Developmental Coordination Disorder (Crawford & Dewey, 2008; Kaplan, Dewey, Crawford & Wilson, 2001). Because each of these other disorders is frequently co-morbid with each other (e.g., reading and communication disorders, reading and motor skills disorder, communication and motor skills disorder), it is difficult to determine how commonly ADHD is associated with any specific developmental disorder or how many developmental disorders may be present in individual cases of ADHD. Large-scale studies on co-morbidity between ADHD and developmental disorders (e.g., Fliers, Vermeulen, Rijdsdijk, Altink, Buschgens, et al., 2009; Martin, Piek & Hay, 2006; Martin, Piek, Baynam, Levy & Hay, 2010) have generally used parent or teacher reports rather than objective testing to assess abilities and have involved twins rather than representative clinical samples.

The problem with ignoring the association between motor, learning or communication problems and symptoms of ADHD is that the association may not be due only to superficial effects (e.g., inattention interfering with learning; inability to understand leading to inattention). Twin and family studies (Fliers et al., 2009; Martin et al., 2006) suggest that motor skills disorder and ADHD have a shared etiology, and family and longitudinal studies (e.g., Kovac et al., 2001; Snowling, Bishop, Snodgrass,

Chipchase, & Kaplan, 2006) show that the presence of either ADHD or specific language impairment represents a risk for the other disorder. These and similar results suggest that one or more underlying impairments directly affects performance in multiple domains.

Unfortunately, DSM-IV definitions of attention deficit and specific developmental disorders are based on the idea, originating with Morgan (1896), that specific congenital defects in brain development are responsible for specific delays in learning to sustain attention, inhibit behaviour, or acquire reading, writing, arithmetic, expressive language, receptive language, or motor skills in the same way that acquired local brain impairments are responsible for various agnosias, aphasias, and apraxias. This modular and static view of developmental disorders is challenged by dynamic models in which the reciprocal interaction of neural systems underpins the acquisition of cognitive abilities (van der Maas, Dolan, Grasman, Wicherts, Huizenga et al., 2006) and brain defects have cascading effects on multiple neural systems (Karmiloff-Smith, 2009; Thelen & Bates, 2003). Cascade effects imply that affected children will not have specific deficits; rather, a range of cognitive functions will be affected depending on which basic processes are impaired and how they are impaired.

To improve our understanding of whether and how specific developmental disorders are related to the symptoms of ADHD, we need more information about the severity and range of deficits that are present among children with ADHD. In this study we estimate the abilities of children with ADHD in five domains: intelligence (perceptual reasoning, verbal comprehension), language (receptive, expressive), motor coordination (fine, gross), social cognition (emotion recognition, emotion understanding, theory of mind), and executive functioning (response inhibition, verbal working memory accuracy/speed). We hypothesise that not only will children with

ADHD obtain significantly lower scores in many of these domains than typically developing children, but also that a larger proportion of children with ADHD will have deficits in one or more of these domains that are large enough to be clinically significant (e.g., one or two standard deviations (SD) below the population mean).

If, as hypothesised, children with ADHD are pervasive low achievers, we expect that correlations among different domains will be substantially stronger in the ADHD group than in a group of typical children. The potential importance of these stronger correlations is that they represent a way to map cognitive domains that are affected by a disorder or a combination of disorders. Finally, we examine whether level of achievement is related to symptoms of ADHD and other disorders among typical children. If attention and performance on ability tests are functionally related in children with ADHD, we can expect that they will also be related in typical children. If attention problems are responsible for poor performance on ability tests, we expect that symptoms of ADHD will be negatively correlated with performance on all ability tests that place demands on attention. However, if only some ability domains are related to ADHD symptoms, this would imply that relationships between performance and attention problems cannot be regarded as the direct consequences of inattentiveness.

Method

Participants

A total of 106 children ranging in age from 6 years 11 months to 14 years 10 months participated in this study. Children in the ADHD group ($n=53$; mean age=10.88 years; $SD=2.07$) were recruited from Perth area schools whose records showed that the children had pediatrician diagnoses of ADHD and were currently receiving treatment for ADHD. In order to provide us with an index of current

symptoms, parents completed the SWAN Rating Scale (Swanson, Schuck, Mann, Carlson, Hartman et al., 2002). The results suggested that 27 children (23 boys) had symptoms consistent with the inattentive subtype (scores >17 on the inattentive scale and <17 on the hyperactivity/impulsivity scale) and 26 children (19 boys) had symptoms consistent with the combined subtype (scores >17 on both the inattentive and hyperactivity/impulsivity scales). Parents reported other disorders that had been diagnosed. Co-morbid learning disorders ($n=2$) and depressive disorders ($n=4$), but no physical disorders likely to affect performance, were reported. All but nine children were taking methylphenidate or dexamphetamine.

Age and sex-matched typically developing comparison children were selected from a larger sample (Dyck et al., 2006) which had been recruited from 42 schools representing the distribution of academic performance in the Perth region. Once a school had agreed to participate, participants were recruited in one of two ways. Parents of children aged 7 to 12 years received letters seeking permission to enrol their child in 'Project KIDS.' Project KIDS is conducted through a child study centre during school holidays, and involves intensive data collection, for one day per child, with small groups of children (see Procedure below). This method resulted in the recruitment of 32 children aged 7 to 12 years. Parents of children aged 6 years or more than 12 years received letters seeking permission to assess their child at the school in which the child was enrolled. This method resulted in the recruitment of the remaining 21 children. The comparison group consisted of 53 children (42 boys) with a mean age of 10.91 years ($SD=2.09$).

Measures

Intelligence was measured with four subscales from the third edition of the *Wechsler Intelligence Scale for Children* (WISC; Wechsler, 1992)—Vocabulary,

Information, Block Design, and Picture Completion. These WISC subtests represent the verbal comprehension and perceptual reasoning components of intelligence and provide a good estimate of full scale IQ. Each test has excellent split-half and test-retest reliability, and both criterion and concurrent validity are well-established (Wechsler). Reliability of the tests in samples of children with a developmental disorder and typical children, respectively, was $\alpha=.92$ and $.93$ for Information, $\alpha=.94$ and $.93$ for Vocabulary, $\alpha=.90$ and $.96$ for Block Design, and $\alpha=.89$ and $.92$ for Picture Completion (Dyck et al., 2006).

Language ability was estimated with four subscales from the third edition of the *Clinical Evaluation of Language Fundamentals* (CELF; Semel et al., 1995)—Concepts and Directions, Word Classes, Recalling Sentences, and Formulated Sentences. The CELF has been standardised across a wide range of ages. Specific scales were selected because they are the only CELF scales that are administered to all age groups and because they sample receptive (Concepts and Directions, Word Classes) and expressive (Recalling Sentences, Formulating Sentences) language. These subscales have acceptable internal consistency ($\alpha=.54$ to $.91$), test-retest reliability ($.69$ to $.87$), and concurrent validity [correlations with earlier versions ($r=.42$ to $.75$) and with the Wechsler scales ($r=.58$ to $.75$) (Semel et al.)]. Reliability in disordered and typical samples, respectively, was $\alpha=.96$ and $.95$ for Concepts and Directions, $\alpha=.93$ and $.95$ for Word Classes, $\alpha=.95$ and $.96$ for Recalling Sentences, and $\alpha=.96$ and $.96$ for Formulating Sentences (Dyck et al., 2006).

Motor coordination was assessed with the *McCarron Assessment of Neuromuscular Development* (MAND; McCarron, 1997). The MAND comprises 10 tasks, of which five assess fine motor skills (Beads in a Box, Beads on a Rod, Nuts and Bolts, Finger Tapping, Rod on Slide) and five assess gross motor skills (Finger

/Nose/Finger, Hand Strength, Heel to Toe Walking, Jumping, One Foot). These tasks have acceptable test-retest reliability (.67 to .98), criterion validity (e.g., prediction of work performance), and concurrent validity [correlations with the O'Connor Finger Dexterity Test ($r=-.41$ to $-.62$), simple reaction time ($r=-.31$ to $-.58$), finger tapping ($r=.35$ to $.53$), and choice reaction time ($r=-.45$ to $-.62$)]. Reliability in disordered and typical samples, respectively was $\alpha=.92$ and $.92$ for Beads in a Box, $\alpha=.86$ and $.89$ for Beads on a Rod, $\alpha=.89$ and $.95$ for Nuts and Bolts, $\alpha=.76$ and $.70$ for Finger Tapping, $\alpha=.70$ and $.64$ for Rod on Slide, $\alpha=.93$ and $.92$ for Finger /Nose/Finger, $\alpha=.68$ and $.91$ for Hand Strength, $\alpha=.94$ and $.84$ for Heel to Toe Walking, $\alpha=.17$ and $.18$ for Jumping, and $\alpha=.82$ and $.86$ for One Foot (Dyck et al., 2006).

Social Cognition. Social cognitive ability was estimated with a combination of three first-order and one second-order theory of mind tasks, an advanced theory of mind task, and six subscales from the Emotion Recognition Scales (Dyck, Ferguson & Shochet, 2001; Dyck, Farrugia, Shochet & Holmes-Brown, 2004). First order *theory of mind* tasks are false belief tasks commonly used to assess differences between children with/without some disorder, and included the "Sally Ann" (Baron-Cohen, Leslie & Frith, 1985), "Smarties" (Perner, Frith, Leslie, & Leekam, 1989; Wimmer & Perner, 1983), and "Ella the Elephant" tasks (Harris, Johnson, Hutton, Andrews, & Cooke, 1989). In each task, a child is asked whether a protagonist will act consistently with the protagonist's beliefs, known to be false, or consistently with what the test-taker knows to be the true state of the world. Responses which indicate action consistent with the protagonist's false beliefs are scored correct. The second-order theory of mind task, the "John and Mary ice-cream story" (Perner & Wimmer, 1985), is identical except that a child must assess what the protagonist thinks that another person thinks. We treated these tasks as separate items on a 4-point theory of mind

scale. The reliability of this scale in disordered and typical samples is relatively poor ($\alpha=.51$ and $.64$; Dyck et al., 2006). The *Strange Stories Test* assesses the ability to provide context-appropriate mental state explanations for non-literal (irony, sarcasm, lies) statements (Happé, 1994). The test is internally consistent in disordered and typical samples ($\alpha=.85$; Dyck et al., 2001).

The Emotion Recognition Scales include three measures of emotion understanding ability. The *Emotion Vocabulary Test* measures the ability to define emotion words (what does the word “angry” mean?). The *Comprehension Test* measures the ability to understand the emotional consequences of exposure to an emotion-eliciting context (Susan is given a new bicycle for her birthday. What will Susan feel?). The *Unexpected Outcomes Test* measures the ability to apply reasoning skills and knowledge of the causes of emotions to explaining apparent incongruities between an emotion-eliciting context and the emotion elicited by the context. Items provide information about a situation that is likely to cause an emotional response in a protagonist (John likes a girl called Susan, and he wants her to go to the movies with him. When he asks her, she says yes). Items then indicate what emotion has been experienced (On their way to the movies, he is very angry). In each case, the emotion differs from what is usually expected to occur in the situation. The test-taker must explain the apparent incongruity. The internal consistency of the three emotion understanding measures in disordered and typical samples, respectively, is: Emotion Vocabulary Test: $\alpha=.86$ and $.84$; Comprehension Test: $\alpha=.78$ and $.79$; Unexpected Outcomes Test: $\alpha=.64$ and $.77$ (Dyck et al., 2001; Dyck, Farrugia et al., 2004).

The Emotion Recognition Scales also include three measures of emotion recognition ability. The *Fluid Emotions Test* (Dyck, Farrugia et al., 2004) measures the ability to recognise static and changed/changing facial expressions of emotion.

This is a computer-presented test and items are drawn from Matsumoto and Ekman's (1995) color slides of adults expressing one of seven emotions (anger, contempt, disgust, fear, happiness, sadness, surprise) or a neutral expression. Each item consists of two head and shoulders pictures of a person expressing one of the seven emotions or a neutral expression. The test-taker is asked what emotion is being expressed in the first picture. After responding, the image is transformed to another person expressing a different emotion. Subjects identify, as quickly as they can, the second emotion. Speed of response is measured with a stop-watch. Two subscales were used: initial accuracy (initial emotions correct) and speed given accuracy, which is based on the speed of accurate post-morph responses. Response latencies greater than 12 seconds are scored 0 whether the response is accurate or not. Latencies of 9 – 12 seconds are scored 1, and each subsequent 1 second decrease in latency results in an incremental score of 1. Latencies less than 4 seconds are scored 7. The internal consistency of the Accuracy and Speed Given Accuracy subscales were observed as $\alpha=.88$ and $\alpha=.88$, respectively, in samples of disordered children, and $\alpha=.65$ and $\alpha=.84$ in typical children (Dyck et al., 2001, 2006; Dyck, Farrugia et al., 2004).

The *Vocal Cues Test* (Dyck, Farrugia et al., 2004) measures the ability to recognise vocal intonations specific to seven different emotions or an emotionally neutral expression. We used the “Unreal” scale in which emotions are expressed using non-semantic content: numerals, letters, nonsense syllables. The internal consistency of the test was $\alpha=.91$ in disordered children and $\alpha=.85$ in typical children (Dyck, Farrugia et al.).

Working memory and response inhibition, two main components of executive functioning, were assessed with a set of computer administered tests. Working memory was assessed with two tasks, a Trailmaking/Updating Memory task and a

Goal Neglect task. The trailmaking task is a simplification of a more complex task (Rabbitt, 1997) and is designed to assess working memory and behavioural inhibition. In this task, the first four letters of the alphabet are designated as the 'target set,' and within this target set, the actual target changes with successive stimulus presentations (i.e., from A to B to C to D to A). Children are required to discriminate whether a letter, presented on screen, is part of the target set, and if it is, whether the letter is the current target. There are two trials of 120 stimulus presentations each, of which 20 presentations are the target stimulus. For each presentation, a blue key is pressed if the stimulus is the target stimulus, otherwise a red key is pressed. We used the mean response time scores from each of two trials of the test.

The goal neglect task measures the ability to formulate and respond to goal-directed plans (Duncan, Emslie & Williams, 1996). It requires that a test-taker disregard a task requirement which has been understood and remembered in order to achieve some other goal. Letters and numbers are presented to the left or the right of a fixation point. Test-takers are asked to read out the stimuli on either the left or the right of the screen, and then either switch to the opposite side if a + sign is presented, or stay on the same side if a – sign is presented. There are six 'switch' and six 'stay' trials. In each trial, the presentation of 10 sets of stimuli (letters/numbers) is followed by the switch or stay cue, and then three additional sets of stimuli. A trial is 'passed' if, before and after the cue, there are more letters called from the correct than the incorrect side, and the number of passes was the measure that we used.

Response inhibition was assessed with a modified version of the Go/No-Go task used by Shue and Douglas (1992) to assess simple motor inhibition. In this task, letters are designated either as 'go' (respond) or 'no-go' (do not respond) stimuli, and are presented at 1-second intervals. When a go stimulus is presented, the child is

required to press a response key as quickly as possible, and when a no-go stimulus is presented, no response is required. There were two trials of the task, each consisting of 120 stimuli (60 'go' and 60 'no-go'). Responses to the 'no-go' stimulus are scored as commission errors, and failures to respond to the 'go' stimulus are scored as omission errors. In each trial, we scored the total number of commission and omission errors.

We estimated the presence and severity of ADHD and others symptoms in the typical children group with the Child Behaviour Checklist (Achenbach, 1991). The rating scale lists 113 symptoms that parents rate as 'not at all true,' 'sometimes true,' or 'mostly true' of their child. Items are combined to form eight primary scales. The subscales include 'aggressive behaviour,' 'delinquent behaviour,' 'anxious / depressed,' 'somatic complaints,' 'withdrawn,' 'social problems,' 'thought problems,' and 'attention problems.' The CBCL also includes a list of 'other problems.'

The SWAN scale assesses the presence of ADHD symptoms of hyperactivity/impulsivity and inattention in the general population (Swanson et al., 2002). The scale comprises 18 items that correspond to the ADHD symptoms listed in DSM-IV (e.g., "Does this child often fail to give close attention to detail and make careless mistakes?"). Items are scored on a 7-point scale from -3 (far above average) to +3 (far below average). Factor analyses carried out by Swanson et al. found that the 18 items of the SWAN load on two factors, accounting for 87% of scale variance, reflecting the inattentive and hyperactive/impulsive symptom dimensions. The SWAN rating scale accurately identifies cases that meet diagnostic criteria for ADHD (Smalley, McGough, Moilanen, Loo, Tanila, et al., 2007; Swanson et al.) and is thought to provide a realistic marker of the ADHD phenotype for genetic research (Hay, Bennett, Levy, Sergeant & Swanson, 2007).

Procedure

This project was approved by the Human Research Ethics Committee at Curtin University. Written consent was obtained from all parents and verbal consent from all children prior to testing. Participants in the ADHD group were individually assessed at their schools. Testing followed a prescribed order and was conducted in three sessions (2.5, 2.5, and 1.25 hours) over two or three days. Parents of children with ADHD were asked to withhold medication on days their children were tested. Participants in the comparison groups aged 7 to 12 years were assessed individually as part of Project KIDS, a project at the University of Western Australia Child Study Centre in which data are collected during school holidays. Participants in the comparison groups aged 6 years, 13 years, or 14 years were assessed individually at their schools. Procedure varied depending on whether the child was or was not assessed as part of Project KIDS.

For children participating in Project KIDS, groups of up to 12 children were scheduled for a full day (8:45 a.m. to 4:30 p.m.) of activities. Upon arrival at the child study centre, children participated in a “getting to know you” activity. Testing was then conducted in three 90-minute sessions, each of which was divided into three 30-minute testing blocks. The first test session was followed by a 30-minute recess, and the second by a 60-minute lunch break. Testing was administered by a team of researchers. During breaks, children were provided with colouring books, pencil puzzles, and age-appropriate movies; they were also given access to an outdoor playground.

The order of test administration was not uniform. Rather, each child had his/her own schedule. Adherence to the test schedule was essential to the smooth running of the program; if scheduled activities could not be completed, they were

deferred to the end of the day where one hour of unallocated time was available to administer deferred tasks. Testing was usually completed within 4.5 hours, but sometimes required up to 5.5 hours. All tests except the executive function tasks were individually administered according to the instructions in the relevant manuals. Children were given individual instructions for the executive function tasks, but performed the tasks in a room with up to four children.

For children not in Project KIDS, testing was done at the school of recruitment. For these children, testing was less rigidly scheduled in order to accommodate the shorter attention span of younger children and to minimise disruption to school activities. Testing followed a standard order designed to maximize task-engagement. Because of test discontinuation rules, younger children usually completed fewer test items, which reduced the total time required. In most cases, testing was completed in a single day; otherwise, testing was completed within two days.

Data Transformations

Previous research has shown that American test norms are inappropriate for West Australian samples, which achieve significantly above the norm on some tests (e.g., the Wechsler scales) and below the norm on others (e.g., the McCarron scales; Dyck, Hay, Anderson, Smith, Piek & Hallmayer, 2004). For example, Piek and Edwards (1997) observed that their sample of 171 children had a mean verbal IQ of 111, Piek, Dworcan, Barrett and Coleman (2000) observed that their sample of 72 children had a mean verbal IQ of 108, Pitcher, Piek and Barrett (2002) observed that their control samples of 39 and 31 children had mean verbal IQs of 108 and 111, respectively, and Dyck, Hay, Anderson, Smith, Piek and Hallmayer (2004) observed a mean verbal IQ of 110. This pattern of results means that it was necessary to rescale

measures of each ability construct to ensure that each standard ability score has the same mean and standard deviation in our sample. To ensure that all ability measures had the same scale, we used data from the representative sample of children from which the comparison groups were selected (Dyck et al., 2006) to create standard scores (mean=100, SD=15) for each variable. These standard scores were then used to create a set of composite scores, an unweighted average of standard scores on tests that have been defined *a priori* as part of the ability domain. The composite variables were as follows: *perceptual reasoning* was the average of Block Design and Picture Completion ($r=.39, p<.01$, in typical children); *verbal comprehension* the average of Vocabulary and Information ($r=.66, p<.01$); *emotion recognition ability* was the average of Accuracy 1, Speed Given Accuracy, and Vocal Cues Test ($r=.27$ to $.55, p<.01$); *emotion understanding ability* was the average of Comprehension Test, Emotion Vocabulary Test, and Unexpected Outcomes Test ($r=.22$ to $.35, p<.01$); *theory of mind ability* was the average of the false belief tasks and Strange Stories Test ($r=.13, p<.01$); *receptive language ability* was the average of Concepts and Directions and Word Classes ($r=.51, p<.01$); *expressive language ability* the average of Formulating Sentences and Recalling Sentences ($r=.52, p<.01$); *fine motor coordination* was the average of fine motor tasks ($r=.11$ to $.49, p<.01$) and *gross motor coordination* the average of the five gross motor tasks ($r=.10$ to $.34, p<.01$; for hand strength, finger nose finger, $r=.01, ns$); *response inhibition* was the average of the two go/no go trials ($r=.50, p<.01$); *verbal working memory accuracy* was the average accuracy score of the two trials of the trailmaking and the goal neglect task ($r=.59$ to $.84, p<.01$) and *verbal working memory speed* was the average response time and response variability of the trailmaking / updating memory tasks ($r=.51$ to $.81, p<.01$).

Composite scores were restandardised by calculating age norms (mean and SD in normative sample) for each composite measure so that each composite score had a mean of 100 and a SD of 15.

Results

Descriptive statistics for ability measures are reported in Table 1. The comparison group had mean scores close to the population mean on all variables except verbal working memory speed. By contrast, the mean scores of the ADHD group were below the population mean on most variables. To assess whether the ADHD and comparison groups differed significantly, we conducted independent t-tests, with Levene's formulas used to assess equality of variances and to adjust t-values and degrees of freedom when variances were unequal. To control for multiple contrasts, alpha was set at .005. These results (see Table 1) show that the ADHD group achieved lower scores than the comparison group on verbal comprehension, expressive and receptive language, gross motor coordination, emotion understanding, and verbal working memory speed tasks.

For several variables, the mean score of the ADHD group was about one SD below the population mean, which implies that many individuals achieved much lower scores. We coded how many participants within each group achieved scores more than two SDs or more than one SD below the population mean. Table 2 shows how many participants within each group exceeded the cut-offs, and Table 3 shows how many participants within each group exceeded how many cut-offs. Children in the ADHD group were twice as likely to have at least one score more than two SDs below the mean [$\chi^2(1)=8.80, p<.01$] and also more likely to have at least one score more than one SD below the mean [$\chi^2(1)=6.01, p<.05$] as the comparison group. Low-scoring children in the ADHD group were four times as likely to have more than

two [$\chi^2(1)=10.03, p<.01$] or three [$\chi^2(1)=4.97, p<.05$] scores below the two SD threshold and two to three times as likely to have two [$\chi^2(1)=13.64, p<.001$] or three scores [$\chi^2(1)=16.06, p<.001$] below the one SD threshold as comparison children. Very low scores were most common where the ADHD and comparison groups differed significantly: verbal comprehension, expressive and receptive language, gross motor coordination, emotion understanding, and verbal working memory speed.

INSERT TABLES 1, 2 AND 3 ABOUT HERE

To assess whether the relatively pervasive low achievement of the ADHD group was associated with stronger correlations between variables in this group, Pearson correlations between the measured domains were calculated separately for each group (see Table 4). Table 4 highlights cases where a correlation differed significantly from zero in one group but not the other group, or, in cases where the correlation differed from zero in both groups, the correlation was significantly stronger in one group than the other. According to these criteria, 27 of 66 coefficients differed across the two groups, and in 24 cases the correlation was stronger in the ADHD group. Correlations differed most often when one of the variables was verbal working memory speed (eight coefficients) or expressive language (seven coefficients), including the correlation between these variables. Apart from correlations involving these variables, the most affected abilities were gross motor skills and emotion understanding ability, each with four stronger coefficients (including between these variables). The three correlations that were stronger in typical children involved correlations between receptive language and both emotion understanding and verbal working memory accuracy, and between this latter variable and working memory speed.

INSERT TABLES 4 AND 5 ABOUT HERE

Finally, data from typical children were used to assess Pearson correlations between ability scores and parent rated attention and other problems (see Table 5). Table 5 shows that the symptom scales most closely related to ADHD (attention, aggression, delinquent behaviour) were significantly correlated with ability scores, especially intelligence, language, and motor skills scores. Across all CBCL scales, symptoms were most commonly associated with poor gross motor coordination (seven significant correlations; $r = -.25$ to $-.40$) and with poor expressive language ability (six significant correlations; $r = -.24$ to $-.33$). In general, social cognition and verbal working memory variables were not related to symptoms.

Discussion

The first aim of this research was to determine the breadth and severity of ability deficits among children with ADHD, partly in order to determine what proportion of these children have clinically significant deficits and what proportion are pervasive low achievers. It was expected that low achievement in the ADHD group would be associated with stronger correlations among ability variables in this group, and that the pattern of stronger than usual correlations would permit us to estimate what cognitive functions might be less differentiated among children with ADHD. The results indicated that children with ADHD typically (85%) have at least one mild ability deficit ($> one SD$ below population mean), usually (55%) have at least one severe deficit ($> two SDs$ below mean), and usually (55%) have pervasive ability deficits (three or more scores $> one SD$ below population means). The results also indicated that a large proportion (45%) of correlations among ability variables are stronger in the ADHD group, especially correlations between expressive language or verbal working memory speed and other variables. This pattern of results suggests that language and executive functions are less well differentiated in a subset of

children with ADHD than in typically developing children, and also suggests that the impairments responsible for this lack of differentiation may contribute directly to the poor language and language-dependent abilities of a subset of children with ADHD.

Co-occurring Ability Deficits or Disorders

DSM-IV (American Psychiatric Association, 2000, p. 88) says that “on average, intellectual level, as assessed by individual IQ tests, is several points lower in children with [ADHD] compared with peers.” Our results indicate that this is not the case in terms of verbal intelligence. On average, verbal intellectual level in the ADHD group was 16 points lower than in the comparison group, and more than half of the ADHD group had scores that placed them below the 15th percentile of their peers. Comparable results were obtained for measures of expressive and receptive language, where 43% and 37%, respectively, of children with ADHD scored below the 15th percentile. Performance on the most language-dependent measures, including emotion understanding and theory of mind tasks, was also poor in the ADHD group, with 33% and 27% of children, respectively, scoring below the 15th percentile. More broadly, children with ADHD were also more likely to have ability deficits on gross motor tasks that make minimal demands on language: 37% of children in the ADHD group scored below the 15th percentile on gross motor tests.

These results are consistent with those of Kaplan et al. (2001) who found that 40% of children with ADHD had one other disorder, 28% had two other disorders and a further 12% had three or more disorders in addition to ADHD. The results are also consistent with research showing that ADHD symptoms are specifically related to deficits in verbal comprehension, receptive and expressive language, and gross motor coordination. Watemberg, Waiserberg, Zuk and Lerman-Sagie (2007) found that 55.2% of a consecutive sample of 91 children with ADHD met diagnostic criteria for

Developmental Coordination Disorder, 23.2 % for Expressive Language Disorder, and 9.5% for Phonological Disorder. Conversely, McGrath, Hutaff-Lee, Scott, Boada, Shriberg, and Pennington (2008) found that among children with a speech sound disorder and specific language impairment, 39% met diagnostic criteria for ADHD. The specific association with language and motor skills problems suggests that in some cases, ADHD symptoms may be functionally related to the conditions responsible for the language or motor skills problems.

Functional Relationships between Language, Motor Skills, and Attention

The relatively pervasive low achievement of children with ADHD implies that correlations between ability variables are stronger in the ADHD group than in the group of typical children (Dyck et al., 2006). Where correlations are stronger, the respective abilities are less independent of each other, or less well differentiated, which means that performance of the respective tasks is achieved by abnormal physiological means compared with typical children (Belmonte & Yurgelun-Todd, 2003). Our results indicate that many abilities are less well differentiated among children with ADHD, and especially that expressive language, the speed of working memory and, to a lesser extent, gross motor and emotion understanding abilities, are more strongly related to each other and to other abilities among children with ADHD. These results are consistent with research pointing to shared impairments across attention, language, and motor skills in attention, language, and motor skills disorders.

There is accumulating evidence that motor skills problems are associated with impaired attention and executive functions (Alloway & Archibald, 2008; Mandich, Buckolz, & Polatajko, 2002, 2003; Martini, Wall, & Shore, 2004; Piek, Dyck, Francis & Conwell, 2007; Piek, Dyck, Nieman, Anderson, Hay et al., 2004; Tsai, Yu, Chen, & Wu, 2009; Wilmot, Brown, & Wann, 2007), and that motor skills disorder and

ADHD have a shared etiology (Fliers, Vermeulen, Risjsdijk, Altink, Buschgens et al., 2009; Martin, Piek, & Hay, 2006). More than a quarter of a century ago, Gillberg and colleagues noted the strong association between disorders of attention, motor control, and perception (DAMP; Gillberg, 1983; Gillberg & Rasmussen, 1982), and noted also that in severe cases, speech and language impairments were also present (Gillberg, 2003). It has subsequently been shown that DAMP—the combination of ADHD and motor skills problems—results in a much poorer prognosis than ADHD alone (Rasmussen & Gillberg, 2000). What this evidence suggests is that motor skills problems should not be discounted as secondary to hyperactivity in a child with ADHD (as suggested in the DSM-IV), but regarded as something which defines the disorder as one that may be more disabling in the long term.

There is less evidence of executive functioning deficits in children with language impairments, but Wisdom, Dyck, Piek, Hay and Hallmayer (2007) found that children with Receptive Expressive Language Disorder had substantial and significant deficits in verbal working memory and response inhibition. Recent research has also provided strong evidence of attention problems in these children. Montgomery, Evans and Gillam (2009) observed that children with a specific language impairment performed more poorly than typical children on auditory sustained attention and attention allocation tasks, and also found that performance on these tasks was correlated with sentence comprehension in the language impairment group. Spaulding, Plante and Vance (2008) found the deficit in sustained attention was specific to auditory tasks under a high attention load condition. Stevens, Sanders and Neville (2008) showed that a deficit in selective auditory attention among children with specific language impairment occurred at the earliest stages of sensory processing. Bishop and McArthur (2005) have shown that although the age-

inappropriate auditory event-related potentials of children with specific language impairment improve over time, they remain age-inappropriate and sometimes have wave forms unlike those of typical children of any age. Whether these auditory problems are sufficient to cause behavioural symptoms of inattention is not known, but our finding that language abilities are significantly related to inattention, aggression, and delinquent behaviour in typical children is consistent with this idea.

Consequence, Co-morbidity or Contributing Cause?

Based on cross-sectional research, neither we nor anyone else can answer the question of whether deficits in language, motor skills, and other abilities among children with ADHD are a consequence of ADHD symptoms, are independent of ADHD, or contribute to causing ADHD symptoms. But the pattern of results is consistent with the idea that some ability deficits and ADHD symptoms are linked to the same underlying impairment, which may also mean that among children with ADHD, the cause of the disorder may differ for children with and without accompanying deficits.

There are several reasons for discounting the idea that other performance deficits are a consequence of ADHD. The first reason is that the frequency and magnitude of deficits in the ADHD group are so great that attributing them to inattention is not credible: severe deficits in intelligence, language, social cognition, and gross motor skills are two to seven times as common among children with ADHD as among typical children. The second reason is that ADHD symptoms are associated with deficits in some, but not all, domains. In typical children, inattentiveness, aggressiveness, and delinquency are correlated with intellectual, language, and motor skills, but not with social cognition or executive functions. Among children with ADHD, low achievement is also not uniform across domains: perceptual organization,

fine motor skills, response inhibition, theory of mind, and working memory accuracy are unaffected, while verbal comprehension, expressive language, and gross motor skills are severely affected. In both groups, language and gross motor skills are most strongly associated with attention symptoms or the disorder. If inattentiveness causes poor performance, given that there are no obvious differences among the tasks in the demands they place on attention, why does it not affect performance in all domains? The third reason why ability deficits are not attributable to ADHD also explains why ability deficits are not independent of ADHD: stronger correlations among variables in the ADHD group indicate that the structure of ability among children with ADHD differs from that observed in typical children. In particular, the speed of working memory and expressive language are more closely related to each other and to other variables in children with ADHD. In children with language and other deficits, inattentiveness may result from the fact that processing of executive tasks has not been differentiated from processing language and other tasks. In children with ADHD but no other substantial deficits, inattentiveness would result from some other impairment.

Limitations

We did not conduct comprehensive clinical assessments of children in our ADHD samples, nor did we conduct follow-up assessments of language, intellectual, or other abilities with complete standardised assessment batteries. This means we cannot be sure that children with poor language, motor skills, or other ability scores would have met diagnostic criteria for any developmental disorder. Because parents of children with ADHD were asked to withhold their children's medication for 18 hours prior to testing, performance on ability tests may have been affected by inattention or other ADHD symptoms. Differences between groups may also have

been due to other uncontrolled factors, including possible group differences in fatigue or effort. Because the children with ADHD were screened to ensure that they currently met behavioural criteria for ADHD, our samples may have been non-representative insofar as they may not have been having therapeutic responses to medication. By implication, it may be non-responders who are more likely to have co-morbid language or motor skills problems.

Conclusions

Inattention and other symptoms of ADHD can adversely affect a child's performance in school and on standard ability tests, and so it has been standard practice to defer assessment of scholastic and other abilities in a child with ADHD until ADHD symptoms have been treated (Pliszka et al., 2007). This practice has been justified because it increases the chance of obtaining reliable and valid estimates of a child's abilities. However, given how frequently delays in acquiring language or motor skills accompany ADHD, this practice results in the under-estimation of the severity and range of developmental problems among children with ADHD. Clinicians may be prevented from recognizing that a child's inattention is due to impairments related to a language or motor skills disorder. It is certainly the case that no speech or language or motor skills disorders were reported by the parents of children in our ADHD sample, despite the severity of language and motor skills problems that we observed in some cases.

Children with ADHD typically have at least mild delays or deficits in verbal comprehension, language, or motor skills. These delays may result from neuropsychological impairments that also affect attention, and so may contribute directly to a child's inattention. These delays may also interact with other impairments responsible for ADHD to make the child's disorder more severe and

more disabling. It is essential that children who have been diagnosed with ADHD undergo comprehensive screening to assess for the presence of developmental delays, especially in the areas of language and motor skills, with which ADHD is differentially associated.

Acknowledgements

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Table 1

Means and standard deviations for composite ability scores by group

	CONTROL	ADHD		
Variable	Mean (SD)	Mean (SD)	<i>t(df)</i>	<i>p</i>
PO	101.46 (16.63)	94.66 (18.17)	2.00 (104)	<i>ns</i>
VC	103.49 (16.83)	86.85 (18.82)	4.79 (104)	.001
EL	101.54 (13.94)	88.18 (19.00)	4.12 (95.41)	.001
RL	99.89 (14.61)	87.93 (15.63)	4.06 (104)	.001
FM	99.82 (12.68)	97.92 (14.16)	0.72 (104)	<i>ns</i>
GM	100.56 (15.33)	89.04 (15.99)	3.78 (104)	.001
ER	99.51 (12.88)	96.36 (16.33)	1.11 (104)	<i>ns</i>
EU	103.15 (16.09)	92.10 (18.78)	3.25 (104)	.002
TM	99.53 (14.17)	93.41 (15.56)	2.11 (104)	<i>ns</i>
RI	98.26 (14.18)	102.32 (13.92)	1.48 (104)	<i>ns</i>
WMA	102.99 (12.31)	102.60 (10.76)	0.17 (104)	<i>ns</i>
WMS	106.93 (10.98)	96.50 (15.79)	3.94 (104)	.001

Abbreviations: PO=Perceptual Organization, VC=Verbal Comprehension,
 EL=Expressive Language, RL=Receptive Language, FM=Fine Motor Coordination,
 GM=Gross Motor Coordination, ER=Emotion Recognition, EU=Emotion
 Understanding, TM=Theory of Mind, RI=Response Inhibition, WMA=Verbal
 Working Memory Accuracy, WMS=Verbal Working Memory Speed

Table 2

Number of participants in each group achieving scores more than 2 and more than 1 standard deviations below the population mean

	CONTROL		ADHD		<2SD		<1SD	
Variable	< 2 SD	< 1 SD	< 2 SD	< 1 SD	$\chi^2(df)$	<i>p</i>	$\chi^2(df)$	<i>p</i>
PO	2	9	8	12	3.97 (1)	.046	0.53 (1)	<i>ns</i>
VC	2	5	9	27	4.97 (1)	.026	21.66 (1)	.001
EL	2	5	13	23	9.39 (1)	.002	15.72 (1)	.001
RL	2	9	4	20	0.70 (1)	<i>ns</i>	5.74 (1)	.017
FM	1	4	1	10	0.00 (1)	<i>ns</i>	2.96 (1)	<i>ns</i>
GM	2	7	9	20	4.97 (1)	.026	8.39 (1)	.004
ER	1	7	4	13	1.88 (1)	<i>ns</i>	2.21 (1)	<i>ns</i>
EU	1	8	7	18	4.86 (1)	.027	5.09 (1)	.024
TM	3	9	6	15	1.09 (1)	<i>ns</i>	1.93 (1)	<i>ns</i>
RI	2	10	0	7	2.03 (1)	<i>ns</i>	0.63 (1)	<i>ns</i>
WMA	2	4	1	2	0.34 (1)	<i>ns</i>	0.70 (1)	<i>ns</i>
WMS	2	1	1	8	3.08 (1)	<i>ns</i>	5.95 (1)	.015
Total	22	78	63	175				

Abbreviations: PO=Perceptual Organization, VC=Verbal Comprehension,

EL=Expressive Language, RL=Receptive Language, FM=Fine Motor Coordination,

GM=Gross Motor Coordination, ER=Emotion Recognition, EU=Emotion

Understanding, TM=Theory of Mind, RI=Response Inhibition, WMA=Verbal

Working Memory Accuracy, WMS=Verbal Working Memory Speed

Table 3

Number of significant ability deficits per participant, by group

	CONTROL		ADHD	
Number of deficits	< 2 SD	< 1 SD	< 2 SD	< 1 SD
0	39	19	24	8
1	10	16	12	8
2	2	8	8	7
3	2	3	4	7
4		2	3	8
5		2		2
6		2	1	5
7		1	1	6
8				1
9				
10				1

Table 4

Correlations between ability scores by sample

		2	3	4	5	6	7	8	9	10	11	12
1. Perceptual Organization	TC	.57**	.08	.35**	.19	-.07	.13	.01	.14	-.08	.09	.04
	ADHD	.59**	.47**	.56**	.34*	.16	.25	.13	.42**	.17	.08	.28*
2. Verbal Comprehension	TC		.33^a	.57**	.21	.00	.28*	.37**	.38**	-.08	.14	.14
	ADHD		.70**^a	.45**	.16	.28*	.45**	.43**	.56**	.01	.05	.42*
3. Expressive Language	TC			.63**	-.00	.05	.15	.49**	.31^a	.09	.05	.07
	ADHD			.62**	.03	.17	.28*	.35**	.58**^a	.36**	.38**	.38**
4. Receptive Language	TC				.18	.09	.20	.51**	.40**	.01	.29*	.16
	ADHD				.14	.15	.24	.19	.49**	.33*	.22	.40**
5. Fine Motor	TC					.59**	.23	.01	.16	-.25	.15	.22
	ADHD					.55**	.40**	.17	.05	.07	-.04	.38**
6. Gross Motor	TC						.03	.02	.12	.07	.17	.17
	ADHD						.38**	.39**	.27*	.01	.00	.37**
7. Emotion Recognition	TC							.26	.12	.03	.21	.33*
	ADHD							.45**	.23	.00	.06	.57**
8. Emotion Understanding	TC								.08	-.04	.17	.15
	ADHD								.30*	.19	.17	.12
9. Theory of Mind	TC									.18	.10	.08
	ADHD									.00	.09	.32*
10. Response Inhibition	TC										.02	-.23
	ADHD										.55**	.00
11. Working Memory Accuracy	TC											.36**
	ADHD											.12
12. Working Memory Speed	TC											
	ADHD											

* significant at the .05 level, two-tailed;

** significant at the .01 level, two-tailed;

^a correlations differ significantly from each other at .10 level, two-tailed.

Correlations that differ significantly from each or differ because a correlation is significant in one sample but not the other are in **bold**.

Abbreviations: TC=Typical Children; ADHD=Attention Deficit/Hyperactivity Disorder.

Table 5

Correlations between ability scores and CBCL symptom scores in typically developing children

	Aggr	AnxDep	Attn	Delq	Other	Social	Somatic	Thought	Wdrn
PO	-.12	.00	-.25*	-.30*	-.11	-.01	-.11	-.00	.04
VC	-.20	-.00	-.31*	-.34*	-.13	-.13	-.11	-.01	.07
EL	-.28*	-.15	-.33*	-.29*	-.26*	-.28*	-.08	-.16	-.24*
RL	-.30*	-.17	-.27*	-.30*	-.25*	-.25*	-.25*	-.19	-.13
FM	-.29*	-.16	-.29*	-.23*	-.18	-.25*	-.31*	-.20	-.09
GM	-.38*	-.33*	-.25*	-.21	-.31*	-.40*	-.31*	-.33*	-.23
ER	-.03	-.04	-.18	-.12	-.16	-.09	.01	-.01	.00
EU	-.04	.01	-.09	-.08	-.00	-.02	-.04	.02	-.00
TM	-.17	-.10	-.07	-.15	-.27*	-.07	-.11	.00	-.01
RI	-.05	.04	-.01	.05	.02	-.01	-.00	.13	.07
WMA	-.03	-.01	.09	.07	-.04	-.02	-.06	-.04	-.00
WMS	-.06	.05	-.00	-.15	.00	-.06	.00	.09	.11

* Correlation is significant at the 0.05 level (1-tailed).

Abbreviations: PO=Perceptual Organization, VCI=Verbal Comprehension,

EL=Expressive Language, RL=Receptive Language, FM=Fine Motor, GM=Gross

Motor, ER=Emotion Recognition, EU=Emotion Understanding, TM=Theory of Mind,

RI=Response Inhibition, WMA=Verbal Working Memory Accuracy, WMS=Verbal

Working Memory Speed