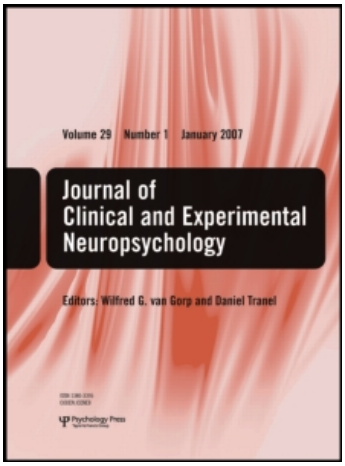

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Childhood Executive Function Inventory (CHEXI): A promising measure for identifying young children with ADHD?

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The present study investigated whether the Childhood Executive Function Inventory (CHEXI) can discriminate between young children fulfilling the diagnostic criteria for attention-deficit/hyperactivity disorder (ADHD) and normally developing children. Unlike other executive function rating instruments, the CHEXI focuses specifically on inhibitory control and working memory, without including items that overlap with the diagnostic criteria of ADHD. The CHEXI was found to discriminate very well between children fulfilling the criteria for ADHD and normally developing children, also when controlling for the effect of IQ and socioeconomic status (SES). Both sensitivity and specificity of the two CHEXI subscales were shown to be high using either parent or teacher ratings. The highest overall classification rate was found for parent ratings on the inhibition subscale, with sensitivity and specificity reaching 93.3. To summarize, the CHEXI should be considered a promising measure for identifying young children with ADHD, although it is for future research to determine whether the CHEXI can be successfully used to also discriminate between different psychopathological groups.

Keywords: Attention-deficit/hyperactivity disorder; Executive function; Working memory; Inhibition; Rating instrument.

A vast amount of previous research has shown that attention-deficit/hyperactivity disorder (ADHD) is a heterogeneous disorder for which executive function (EF) deficits constitute one important aspect (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Nigg, 2006; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2004). The strong association between ADHD and EF deficits has led to the development of a myriad of different neuropsychological tests designed to capture both executive functioning in general and specific abilities within the EF domain, even in children as young as 2–3 years of age (e.g., Carlson, 2005; Hughes & Ensor, 2005; Zelazo & Müller, 2002). However, there are few EF rating instruments available. Compared to neuropsychological tests, rating instruments generally capture more global aspects of behavior. Although they have the disadvantage of suffering from rater biases (cf. Denckla, 2002), ratings have the advantage of capturing behavior over an extended period of time, and as they are easy to administer, ratings can be most valuable as a screening instrument for identifying children at risk of developing psychiatric disorders.

A serious limitation of most available EF rating instruments is, however, that they include not only items measuring different EF constructs such as working memory and inhibitory control, but also items that are nearly identical to the diagnostic criteria for ADHD (*Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition,* DSM-IV; American Psychiatric Association, 1994). Items such as "is impulsive" and "has a short attention span" are, for example, included in the Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia, Andrews Epsy, & Isquith, 2003), which is the most commonly used EF rating instrument.

As the behaviors associated with ADHD (i.e., hyperactivity, impulsivity, and inattention) are relatively common even in normally developing children, distinguishing between age-appropriate behavior and early symptoms of behavior problems has proven to be difficult,

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at least in young children (cf. Campbell, 2002; Carlson, 2005). EFs, which have been presented as potential endophenotypes for ADHD (e.g., Doyle et al., 2005), may have greater discriminant validity. Unlike other EF rating instruments, The Childhood Executive Functioning Inventory (CHEXI; Thorell & Nyberg, 2008) was developed with the aim of focusing more specifically on different types of executive control rather than more general statements or items directly related to the symptom criteria for ADHD. In the present study, we examined the clinical utility of the CHEXI as an instrument for discriminating between young children fulfilling the diagnostic criteria for ADHD and normally developing controls.

The CHEXI includes four subscales measuring inhibition, regulation, working memory, and planning, although a previous factor analysis of both parent and teacher ratings (Thorell & Nyberg, 2008) yielded two broad factors referred to as inhibition (inhibition and regulation subscales) and working memory (working memory and planning subscales). Test–retest reliability for the CHEXI has been shown to be adequate (r = .85 using parent ratings collected on average 3 weeks apart).

No previous studies have collected ratings on the CHEXI for clinical groups, and the discriminant validity of this rating instrument is therefore unknown. Using the BRIEF, significant group differences have been found between normally developing controls and various clinical groups such as children or adolescents with ADHD (e.g., Gioia, Isquith, Kenworthy, & Barton, 2002; Mahone et al., 2002), traumatic brain injuries (Mangeot, Armstrong, Colvin, Yeates, & Taylor, 2002), Tourette syndrome (Mahone et al., 2002), and bipolar disorder (Shear, DelBello, Rosenberg, & Strakowski, 2002). However, group differences alone are insufficient indices of the discriminant validity of a measure, and such analyses need to be complemented with measures of sensitivity and specificity (c.f., Doyle, Biederman, Seidman, Weber, & Farone, 2000). Sensitivity refers to the probability of an abnormal test score, given that a person has the diagnosis in question (i.e., number of true positives divided by the total number of diagnosed children), whereas specificity is defined as the probability of a normal test score given that the person does not have the diagnosis (i.e., the number of true negatives divided by the total number of children without the disorder). In this study, we have also chosen to report the overall classification rate (i.e., the total number of children correctly classified) as this provides the reader with an easily interpretable measure that takes both the measure's sensitivity and its specificity into account.

One study that did determine specificity and sensitivity using discriminant function analyses was conducted by McCandless and O'Laughlin (2007). They studied the BRIEF in a group of children diagnosed with different ADHD subtypes (n = 45) and a comparison group (n = 25) and found overall classification rate of 77.1% for the ADHD versus non-ADHD comparison, with a sensitivity of 77.8% and a specificity of 76.0%. Compared to studies investigating the discriminant validity of neuropsychological EF tests, these results are similar with regard to specificity, but neuropsychological tests have generally been shown to have poorer sensitivity (Barkley & Grodzinsky, 1994; Doyle et al., 2000; Perugini, Harvey, Lovejoy, Sandstrom, & Webb, 2000). The fact that neuropsychological EF tests have been found to be better at excluding normal children from the ADHD category than at confirming ADHD in children with the disorder might be explained by the fact that ADHD is a heterogeneous disorder with multiple pathways and that only a subgroup of children with the disorder have EF deficits (e.g., Castellanos et al., 2006; Nigg, 2006; Nigg et al., 2004). Thus, all children with ADHD should not be expected to have EF deficits. EF rating instruments might therefore serve the purpose of identifying ADHD subgroups of children with EF deficits, who in turn may be helped by targeted intervention programs focused on training executive functions (e.g., Klingberg et al., 2005; Thorell et al., 2009).

Aim of the present study

The aim of the present study was to examine whether the CHEXI is a sensitive measure for discriminating between children fulfilling the diagnostic criteria for ADHD and normally developing children. As it is especially valuable to be able to discriminate between children with psychiatric problems and normally developing children at an early age, preferably even using the rating instrument as a screening tool, the present study included a young sample of children aged 5–8 years.

METHOD

Participants and procedure

The present study included children recruited from two different samples—an at-risk sample and a population-based sample. A first group of children (n = 22) were recruited from local Child Care Centers in Uppsala County, Sweden, at age 5, and all children had been identified by a child psychologist as being at high risk of developing ADHD and/or oppositional defiant disorder (ODD). Out of these 22 children, 17 were shown to meet the symptom criteria for ADHD (i.e., 6 symptoms of inattention and/or 6 symptoms of hyperactivity/impulsivity) based on parent and/or teacher ratings on the DSM-IV rating scale (DuPaul, Power, Anastopoulos, & Reid, 1998). Approximately two years later (age: M = 7 years, 6 months; SD = 0.47) parent and teacher ratings on the CHEXI were collected. At this follow-up, 2 of the children who had been identified at Time 1 no longer met the symptom criteria for ADHD, and these two children were therefore excluded from further analyses. The remaining 15 children met the symptom criteria, the age of onset criterion (i.e., <7 years) the pervasiveness criterion (symptoms present in two settings), and the duration criterion (>6 months) for ADHD according to DSM-IV (American Psychiatric Association, 1994), and these children are hereafter referred to as the ADHD group.

The comparison group (n = 30) was recruited to the longitudinal study at the same time as the ADHD group. The comparison group was recruited from the local birth register of Uppsala County, Sweden, and this group consisted of children who, according to parent reports, had not been diagnosed with any psychiatric disorder or referred to a psychiatric clinic. The comparison group was individually matched to the children in the ADHD group (i.e., 2 comparison children for each child in the ADHD group) with regard to age and gender. None of the children in the study received medical treatment for their behavior problems.

Questionnaire

The CHEXI was developed by Thorell and Nyberg (2008) as a measure focusing specifically on executive functioning. It can be used by either parents or teachers and includes 24 items that can be divided into four a priori subscales: working memory (9 items, e.g., "has difficulty understanding verbal instructions unless he/she is also shown *how* to do something"), planning (4 items, e.g., "has difficulty with task or activities that involve several steps"), inhibition (6 items, e.g., "has difficulty holding back his/her activity despite being told to do so"), and regulation (5 items, e.g., "has clear difficulties doing things he/she finds boring"). These scales correspond to the EF domains presented in Barkley's (1997) hybrid model as constituting the major deficits in ADHD. Factor analysis of either parent or teacher ratings (Thorell & Nyberg, 2008) has yielded two broad factors named working memory (mean value of items measuring working memory and planning) and inhibition (mean value of items measuring inhibition and regulation). In the present study, the data are therefore analyzed for these two global scales. However, separate analyses of all four a priori subscales resulted in similar findings. One child in the comparison group had missing data on all teacher ratings because the parents did not give us permission to contact the child's teacher.

Control variables

We controlled for intelligence (IQ) and socioeconomic status (SES) in the logistic regression analyses. IQ was measured using the Block Design and the Information subtests from the Wechsler Intelligence Scale for Children–Third Edition (WISC–III; Wechsler, 1994). These subtests have been shown to correlate highly with the Full Scale IQ (Block Design: r = .74; Information: r = .78; Wechsler, 1991). An aggregated measure of standard scores (i.e., the raw scores corrected for the child's chronological age) on the Block Design and the Information subtests was used as a measure of intelligence. The Wechsler Intelligence Scale for Children–Fourth Edition (WISC–IV) was not used as this version was not yet available in Swedish at the time of the study. With regard to SES, we collected data on maternal and paternal education using a 3-point scale, and the mean value was used as a proxy variable for SES. If the child only lived with one if his/her parents, the education level of that parent was used in the analyses.

Statistical analyses

Group differences in executive functioning were first studied using t tests. Levene's test for equality of variances was used, and in cases where the variances were unequal, Satterthwaite's approximation for the degrees of freedom was used to calculate the significance level. In addition, group comparisons were complemented with effect sizes using Cohen's (1988) effect size formula (d), where an effect size of .20 is considered as small, an effect of .50 as medium, and an effect of .80 as large. Thereafter, the discriminant validity of the CHEXI was studied using logistic regression analyses. Separate regression analyses were conducted for parent and teacher ratings, and we controlled for the effect of intelligence and SES in these analyses. Finally, measures of sensitivity, specificity, and overall classification rate were calculated.

RESULTS

Means and standard deviations for all the CHEXI subscales are shown in Table 1. This table also presents the results of t tests examining group differences and effect sizes for these comparisons. The results showed that the children in the ADHD group differed significantly from the comparison group on both the CHEXI inhibition and the working memory subscale, and the size of the effects were well above the cutoff for what is normally considered a large effect size.

The results of the logistic regression analyses showed that using parent ratings (Model A) or teacher ratings (Model B), both the CHEXI inhibition and working memory scales contributed significantly (χ^2 ranged between 4.44 and 12.30, ps < .05) to distinguishing between the ADHD group and the comparison group. The same results were found when controlling for intelligence. When using both intelligence and SES as covariates, the effect of the CHEXI working memory scale remained significant for both parent and teacher ratings. For the CHEXI inhibition scale, the effect remained significant for teacher ratings, but was marginally significant (p = .067) for parent ratings. As can be seen in Table 2, the sensitivity (range .73 to .93) and the specificity (range .79 to .93) were high for both parent (Model A) and teacher ratings (Model B). The highest classification rate was obtained for parent ratings on the inhibition subscale, with 93.3% of the children being correctly classified. This meant that only one child in the ADHD group and only two children in the comparison group were misclassified based on parent ratings on the inhibition scale.

Finally, the interrater agreement between parents and teachers was examined by investigating whether the two raters identified the same children as belonging to the ADHD group or the comparison group. The results of these analyses showed that parents and teachers classified 83% of the children in the same category based on

TABLE 1
Means and standard deviations for the CHEXI subscales for the ADHD group and the comparison group, results of *t* tests, and effect sizes

		ADHD group (n = 15)		*Comparison group (n = 29–30)*			
Ratings	*Subscale*	*M*	*SD*	*M*	*SD*	*t value*	*ES*
Parent	Inhibition	4.10	0.41	2.28	0.72	10.95***	2.95
	Working memory	3.41	0.90	1.87	0.69	6.37***	2.03
Teacher	Inhibition	3.73	0.60	1.90	0.93	6.80***	2.23
	Working memory	2.85	0.80	1.62	0.63	5.58***	1.79

Note. CHEXI = Childhood Executive Function Inventory. ADHD = attention-deficit/hyperactivity disorder. ES = effect size.
***$p < .001$.

TABLE 2
Estimates of sensitivity, specificity, and overall classification rate

Model	*Subscale*	*Sensitivity*	*Specificity*	*Classification rate*
A. Parent ratings	Inhibition	93.3	93.3	93.3
	Working memory	73.3	80.0	77.8
B. Teacher ratings	Inhibition	86.7	82.8	84.1
	Working memory	80.0	79.3	79.5
C. Either parent or teacher ratings	Inhibition	100.0	79.3	86.4
	Working memory	100.0	72.4	81.8
D. Both parent and teacher ratings	Inhibition	80.0	96.6	90.1
	Working memory	73.3	86.2	81.8

the inhibition subscale and 72% of the children in the same category based on the working memory subscale. When studying sensitivity and specificity using the combined information from parents and teachers (see Table 2), it was found that for children being identified as cases by either parents or teachers (Model C), sensitivity was perfect for both subscales, although the specificity was then naturally decreased. For children being identified as cases by both parent and teachers (Model D) the specificity was increased, although at the cost of decreasing sensitivity.

DISCUSSION

The major finding of the present study is that the CHEXI, which is a new rating instrument of executive functioning, was shown to discriminate very well between children with ADHD and normally developing controls. This was true also when controlling for the effect of IQ and SES. The classification rate of the CHEXI was even higher than what has been found using other EF rating instruments. This is particularly interesting in view of the fact that the CHEXI focuses specifically on items measuring the EF constructs of inhibition and working memory, whereas other instruments include items that are similar to the DSM-IV criteria for ADHD.

The discriminant validity of the CHEXI was found to be relatively high for both subscales and for parent as well as teacher ratings. However, the classification rate was somewhat higher for the inhibition subscale than for the working memory subscale, especially with regard to parent ratings. This finding is in line with Barkley's (1997) hybrid model of ADHD, which emphasizes inhibition as the primary deficit in ADHD, especially in young children. This is also in line with several previous empirical studies of ADHD symptoms and neuropsychological EF tests (Brocki & Bohlin, 2006; Brocki, Nyberg, Thorell, & Bohlin, 2007; Sonuga-Barke, Dalen, Daley, & Remington, 2002), which have shown that ADHD symptoms are primarily related to deficient inhibition among preschoolers and young school-aged children, whereas relations to more advanced cognitive functions such as working memory and planning are found in older school-aged children. Thus, the discriminant validity of the different CHEXI subscales may vary with the age of the child.

With regard to parent–teacher agreement, the results showed that parents and teachers partially identified different children as having EF deficits. This means that sensitivity could be improved by identifying a child as having EF deficits on either parent or teacher ratings, and specificity could be improved by identifying a child as a case only if EF deficits were reported by both the parent and the teacher. Unfortunately, increased sensitivity always means decreased specificity and vice versa. By providing our readers with different ways of combining the information obtained from parents and teachers, future users of the CHEXI can choose the levels of sensitivity and specificity most suitable for his or her needs.

When comparing the CHEXI with neuropsychological tests, it is interesting to note that the discriminant

validity for the CHEXI was much higher than that found for neuropsychological tests of inhibition and working memory (e.g., Barkley & Grodzinsky, 1994; Doyle et al., 2000; Perugini et al., 2000). We feel that it is important to emphasize that this finding should not be taken to mean that ratings should replace the use of neuropsychological tests. Instead, the relatively modest correlations found between neuropsychological tests and EF ratings using either the CHEXI (Thorell & Nyberg, 2008) or the BRIEF (Anderson, Anderson, Northam, Jacobs, & Mikiewicz, 2002), indicate that information from ratings and neuropsychological tests capture different aspects and that these two types of measure should preferably be used in combination. Ratings have the advantage of being both easy and fast to administer to large groups of children, perhaps as an early screening instrument, whereas neuropsychological tests can provide more in-depth information regarding specific cognitive deficits in children identified as "at risk" using ratings. Another reason why the CHEXI could be valuable as a screening instrument relates to the fact that, compared to other rating instruments such as the ADHD Rating Scale-IV (e.g., DuPaul et al., 1998), the CHEXI is most likely easier for parents and teachers to understand and accept as it focuses on the child's behavior in specific everyday situations rather than on the diagnostic criteria for ADHD as they are presented in DSM-IV (American Psychiatric Association, 1994).

A final important issue concerns our finding that a large number of children in the ADHD group was correctly classified with the CHEXI even though it has been argued that only a subgroup of children with ADHD have EF difficulties (e.g., Castellanos et al., 2006; Nigg et al., 2004). One possibility is that children who are clinically identified at an early age (as was the case in the present study) are more seriously affected in terms of neuropsychological deficits (cf. Wilens et al., 2002).

To summarize, the results of the present study indicate that the CHEXI should be viewed as a promising measure for identifying young children with ADHD. However, the results need to be replicated using a larger sample, and it also needs to be determined whether the CHEXI can be used to discriminate between children of various pathological conditions. The results of the present study also set the stage for future studies to collect normative data from a large number of children at various ages to determine specific cutoffs so that the CHEXI can be used in clinical practice. Finally, it is for future studies to investigate the discriminant validity of the CHEXI in a longitudinal perspective. More specifically, it would be valuable to study whether the CHEXI can be used to discriminate between preschool children with high levels of ADHD who will show continuing behavior problems and children whose behavior problems are more transient in nature.

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