Journal of the International Neuropsychological Society (2012), **18**, 728–737.

doi:10.1017/S1355617712000355

Set-Shifting in Adults with ADHD

Helene Barone Halleland,[1,2,3] Jan Haavik,[2,4,5] AND Astri J. Lundervold[1,2]

[1]Department of Biological and Medical Psychology, University of Bergen, Norway
[2]K.G. Jebsen Centre for Research on Neuropsychiatric Disorders, Bergen, Norway
[3]Solli Hospital, Bergen, Norway
[4]Department of Biomedicine, University of Bergen, Norway
[5]Department of Psychiatry, Haukeland University Hospital, Bergen, Norway

(RECEIVED June 28, 2011; FINAL REVISION February 22, 2012; ACCEPTED February 22, 2012)

Abstract

Difficulties related to inhibition and set-shifting have been suggested as possible endophenotypes of Attention Deficit Hyperactivity Disorder (ADHD). However, such difficulties have not been consistently found in studies using standard neuropsychological tests. This has been partly explained by the complexity of these tests and the need to include contrast measures which control for more basic functions. The purpose of the present study was to examine whether difficulties related to inhibition and set-shifting in adult ADHD patients could be revealed by the Color Word Interference Test (CWIT) from the Delis Kaplan Executive Function System (D-KEFS). A clinically recruited group of adults with ADHD ($n = 60$) obtained significantly lower scores than population derived controls ($n = 60$) on both primary summary ($p < .001$) and contrast measures ($p = .004$) of set-shifting. The differences between the groups remained statistically significant after controlling for intellectual function and working memory ($p = .003$). However, no significant differences between the groups were observed on any measure of inhibition. The study indicates that adults with ADHD have specific difficulties with set-shifting as measured by the CWIT, difficulties that probably also reflect problems related to executive function in their daily life. (*JINS*, 2012, *18*, 728–737)

Keywords: Executive functioning, D-KEFS, Contrast scores, Attention deficit hyperactivity disorder, Pure measures, Stroop test

INTRODUCTION

Attention deficit hyperactivity disorder (ADHD) is a neuropsychiatric disorder characterized by hyperactivity, inattention and impulsivity. Traditionally, ADHD has been described as a child psychiatry diagnosis, but research has shown that a large proportion of children with ADHD have persisting symptoms into adulthood (Faraone & Biederman, 2005; Lara et al., 2009; Mick, Faraone, & Biederman, 2004; Rasmussen & Gillberg, 2000). Although not shown by all individuals within the diagnostic group (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), impairments of executive functioning (EF) have frequently been reported in ADHD (Barkley, 2010; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006).

Deficits in more basic functions have not been adequately addressed in all models of EF in ADHD, despite the fact that lower-order processes are necessary components of higher-order cognitive operations (Rommelse & Buitelaar, 2008). For this reason, it is unclear how much of the variance in EF is due to variance in lower order processes. Tests of EF typically involve cognitive functions at different levels of information processing, only some of which probably reflect the intended function (Anderson, 2002; Castellanos et al., 2006). It is, therefore, important to include control tasks (Denckla, 1996) in studies of EF in individuals with ADHD. It is also a challenge that such studies often include neuropsychological tests originally designed to differentiate between individuals with brain damage and normal controls: These tests may, therefore, be insensitive to the mild cognitive difficulties commonly seen in individuals with ADHD.

The Delis-Kaplan Executive Function System (D-KEFS) (Delis, Kaplan, & Kramer, 2001) was developed to deal with such shortcomings. The test battery enables more sensitive and "pure" measures of EF by including more demanding subtests to prevent ceiling effects and by calculating contrast scores to control for basic functions. One of the few studies of ADHD that included tests from D-KEFS showed that measures from the Color Word Interference Test (CWIT),

Correspondence and reprint requests to: Helene Barone Halleland, Department of Biological and Medical Psychology, University of Bergen, PO Box 7807, NO-5020 Bergen. E-mail: helene.halleland@psych.uib.no

a variant of the original Stroop test, separated children with ADHD from controls (Wodka et al., 2008). This test measures response inhibition, which has been described as a core symptom (Barkley, 1997b, 1997c) and as one of the most promising endophenotypes for ADHD, defined as "heritable, quantitative traits that index an individual's liability to develop or manifest a given disease" (Castellanos & Tannock, 2002). Although ADHD is thought to be associated with dysfunctional inhibitory processes, inhibition has not been consistently defined across cognitive theories (Nigg, 2001). In addition, it has been difficult to compare the results of studies that have used different tests. Thus, it is imperative to develop coherent, widely accepted test definitions and to implement tests that include valid measures of the inhibition effect.

CWIT also includes a measure of set-shifting. Set-shifting, defined as the ability to move back and forth between multiple tasks, operations and mental sets (Miyake et al., 2000), has been described as another potential endophenotype for ADHD (Boonstra et al., 2008). Several studies have investigated set-shifting in ADHD (Barkley, Murphy, & Fisher, 2008; Piek, Dyck, Francis, & Conwell, 2007; Rohlf et al., 2012), but the results have been inconclusive. Tests designed to measure this function have been criticized for having an inadequate level of difficulty, especially for adults, leading to a ceiling effect. Furthermore, most of the research on executive functioning in ADHD has focused on children; more studies are needed to clarify the role of set-shifting abilities in adults.

The CWIT includes two control conditions that measure more basic functions. The third is designed to measure inhibition and the fourth designed to measure both inhibition and set-shifting. However, it is still unclear how much of the variance in the two latter conditions are explained by the two more basic conditions, and how much of the variance in condition 4 are due to condition 3. Studies investigating this relationship with appropriate contrast measures are, therefore, warranted. A strength of D-KEFS is that it includes standardized contrast scores and that the basic functions can be controlled for by running regression analyses (Kramer et al., 2007; Pa et al., 2010).

Inhibition and set-shifting are not only influenced by more basic functions, but also by the individual's working memory and intellectual abilities (IQ). Kramer et al. (2007) have suggested that set-shifting is anatomically and functionally related to working memory because the subjects need to attend simultaneously to multiple task parameters, track progress and maintain task instructions online. However, both the results from Kramer et al. and results from other studies indicate that, despite this overlap, set-shifting seems to represent a distinct construct (e.g., Ravizza & Ciranni, 2002). The influence of IQ on tests of EF (e.g., Adolfsdottir, Sorensen, & Lundervold, 2008) and ADHD symptoms (Barkley, 1997a; Tillman, Bohlin, Sorensen, & Lundervold, 2009) are documented in studies of children. However, inclusion of working memory and IQ as covariates may also remove some of the variance caused by the disorder itself (Barkley, 1997a). On this background, it has been suggested that results should be presented both with and without relevant covariates (Barkley, 1997a).

In the present study, we first compared inhibition and set-shifting in adults with ADHD and a group of controls by analyzing their CWIT performance. From studies of children we expected the ADHD group to be more impaired than a control group on primary summary measures of inhibition and set-shifting. Second, we investigated contrast scores, both those calculated according to the D-KEFS manual, and standard residuals calculated from raw scores obtained by our Norwegian sample. Finally, we asked if group differences would remain when including IQ and working memory as covariates in the statistical analyses.

METHODS

Participants in the Parent Study

The participants with ADHD (>18 years old) were recruited as part of a study that included participants from a national registry of adults diagnosed in Norway from 1997 to May 2005. Diagnostic assessment was conducted by three national expert committees for ADHD/hyperkinetic disorder. Three to five clinicians (mainly psychiatrists and psychologists) with specialized experience in diagnosing ADHD in children and adults served on the committees. Patients were referred to the committees by their psychiatrists, general practitioners or hospital doctors. The procedure for the referral required patient records with thorough descriptions of current symptoms and functioning, comparent information about childhood behavior and functioning and results from both physical and psychiatric examinations. The committees reviewed the patients' records to confirm or disprove the diagnosis of ADHD.

ICD-10 is the official diagnostic system in Norway. However, allowance was made for the diagnosis of the inattentive subtype in DSM-IV. A total of 1700 invitation letters were sent to adults with ADHD between 2005 and 2007, mainly targeting individuals referred after the year 2000. Psychiatrists and psychologists nation-wide were also invited to recruit adults with ADHD who were formally diagnosed according to the national guidelines based on the criteria used by the expert teams, but without the mandatory evaluation of the committees.

The control group was recruited through the database of the Medical Birth Registry of Norway (MBRN), which includes all individuals born in Norway after January 1, 1967. A total of 2963 invitation letters were sent to a randomly selected nation-wide sample aged between 18 and 40 years old. In addition, a subsample was recruited by means of local advertisements. The control group was not screened for ADHD before entering the study. Although this may have led to reduced power, the prevalence of ADHD in this group is assumed to be lower than 5%. This was supported by the estimated prevalence of 1.7% in a population based study of 8- to 10-year-old Norwegian children (Heiervang et al., 2007).

All participants, those with ADHD and the controls, were asked to complete a set of questionnaires. The project was

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

approved by the Regional Committee for Medical and Health Research Ethics of Western Norway (IRB 00001872) and the Norwegian Social Science Data Services (NSD). For other details concerning recruitment and sample of the parent study, see Halleland, Lundervold, Halmoy, Haavik, and Johansson (2009), Johansson et al. (2008), Halmoy et al. (2010), and Lundervold et al. (2011).

When the present study was conducted, the parent study included 572 adults with ADHD and a control group of 895 ethnically matched adults. In the control group, 700 individuals were recruited through MBRN and the rest through advertisements. In the ADHD group, 352 were recruited from the expert teams and the rest by clinicians. According to the Adult ADHD Self-Report Scale (ASRS) screening questionnaire, 18.1% of the ADHD patients were classified as belonging to the inattentive subtype, while 4.8% were classified as inattentive in the control group. Cutoff values were defined as 21 points on this subscale according to the description by Kessler et al. (2005).

Participants in the Present Study

Participants from the parent study (64 with an ADHD diagnosis and 61 controls) were randomly selected from those living in the city and the geographical area close to Bergen. The participants were invited to take part in a neuropsychological examination, which was performed by a trained test technician. Sixteen percent of the individuals with ADHD and 19% of the controls who were invited declined to participate. The control group included 44 individuals who were originally recruited from the MBRN and 17 by advertisement.

Subjects with IQ below 80 ($N = 2$, both from ADHD group) and participants with autism spectrum disorder, tics, Tourette's syndrome or epilepsy ($N = 3$, two from ADHD group) were excluded.

In the ADHD group, 67.3% used central stimulants or other medication for ADHD. They were instructed not to take any of those medications during the day of testing.

Questionnaires/Tests

Self-report questionnaires

Wender Utah Rating Scale (WURS: Ward, Wender, & Reimherr, 1993) was used to measure ADHD symptoms in childhood and the ASRS (Kessler et al., 2005) was used to assess current ADHD symptoms.

Screening questions

The participants answered 31 questions concerning sociodemographic and clinical factors. Information about life-time comorbidities was collected by asking the participants about other disorders, including bipolar disorder, depression/anxiety, reading/writing difficulties, etc. The validity of these self-reported diagnoses was recently reported (Halmoy et al., 2010).

Psychiatric interview

The semi-structured diagnostic interview MINI Plus version 5.0.0 (Sheehan et al., 1998) was used by psychiatrists to assess current substance abuse/dependence and current depressive/manic episode.

Color Word Interference Test (CWIT) from D-KEFS

Primary summary scores

The test includes four conditions: (1) Color Naming, (2) Word Reading, (3) Inhibition, and (4) Inhibition/Switching. In the first condition, the task is to name color patches as fast as possible. In the second condition, the task is to read color words as fast as possible. The two first conditions measure basic lower-level cognitive skills of color naming and reading. The third and fourth conditions measure higher level cognitive functioning (i.e., aspects of EF). Inhibition is measured by the third condition, where the task is to inhibit reading words denoting colors while naming the incongruent color of the word. In the fourth condition, the test person is asked to alternate between inhibiting an automatic response of reading (as in the third condition) and reading the color word if the word is framed. This condition, therefore, requires both inhibition and set-shifting abilities. In the present study, we will refer to these primary subtests as condition 1 through 4.

Primary contrast scores

To obtain more pure measures of inhibition and inhibition/set-shifting, the D-KEFS manual offers contrast scores that control for more basic conditions. The scaled scores for basic conditions are subtracted from the scaled scores on measures of higher cognitive functions. Then, this difference score is transformed to a scaled score corrected for age according to US norms. The contrast scores include the following: (1) condition 3 minus condition 1, (2) condition 4 minus the sum of condition 1 and 2, and (3) condition 4 minus condition 3; the contrast scores were included in the present study, referred to as P-inhibition, P-inhibition/set-shifting and P-set-shifting, respectively.

Standardized residual (SR) scores for inhibition and set-shifting

Contrast measures were also calculated as residuals from raw scores (Kramer et al., 2007; Pa et al., 2010). The "higher order" skills were regressed on the "lower order" ones by using a linear regression analysis for each variable (cfr. the paragraph on statistical analyses for more details) to generate standard residuals of inhibition (SR-inhibition), inhibition/set-shifting (SR-inhibition/set-shifting) and set-shifting (SR-set-shifting).

Wechsler Abbreviated Scale of Intelligence

Two subtests (Matrix Reasoning and Vocabulary) from the Wechsler Abbreviated Scale of Intelligence (WASI) were

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

used as an estimate of IQ according to the norms presented in the test manual (Wechsler, 1999).

Paced Auditory Serial Addition Task

Paced Auditory Serial Addition Task (PASAT: Gronwall, 1977) was used to measure working memory. Participants were presented (auditory) a number between 1 and 9 every third second, and should always add the two last numbers. Working memory was defined as the total number of correct responses. PASAT requires active manipulation of stimuli in which an action is required on the presented stimuli. Gallagher and Blader (2001) point out that problems with working memory under stressful conditions, as the one measured by the PASAT, are common in individuals with ADHD.

Statistical Analyses

SPSS, version 15.0, was used for statistical analyses. Analyses were run both with and without outliers. For the D-KEFS primary conditions and primary contrast scores, outliers were defined as more than three interquartile ranges from the rest of the scores. Four univariate outliers and two multivariate outliers were found. No outliers were found for the primary contrast scores. In the regression analyses, standard residuals more than 3.3 or less than −3.3 were defined as outliers and removed. No outliers were found for the SR-inhibition measure, while three outliers were found for SR-inhibition/set-shifting and SR-set-shifting (all from the ADHD group). New regression analyses were run for the conditions where outliers were found, and one new outlier (from the ADHD group) was identified. This was also removed, and new analyses were run. All subsequent analyses were run both with and without outliers. The results were similar with regard to significance, and, therefore, only results from analyses without correction for outliers will be presented. As it is difficult to determine if working memory and total IQ also remove some of the variance caused by the disorder itself, the analyses were run both with and without the two variables as covariates.

Socio-demographic and clinical data

One-way analysis of variance (ANOVA) and χ^2 analyses were used to examine group differences for socio-demographical and clinical data.

Primary summary conditions

The assumption of Equality of Covariance (Box's Test of Equality of Covariance Matrices) was not met and the Equality of Error Variances (Levene's Test of Equality of Error Variances) was not met for CWIT condition 1, 2, and 4. An alpha level of $p < .01$ was, therefore, set when interpreting these results. Factorial MANCOVAs with age as a covariate were used to examine group differences regarding the raw scores of the four primary conditions. Significant multivariate results were followed by Bonferroni-corrected univariate tests (ANCOVAs). The alpha level was defined by dividing 0.05 (or 0.01 if violation of assumptions) by the number of comparisons within each set of analyses to avoid type 1 error. Age was used as a covariate in all analyses. For significant results, working memory and IQ were added as covariates.

Primary contrast scores

The primary contrast scores between the two groups were investigated with separate ANOVAs. ANCOVAs were performed to control for IQ and working memory on significant results. The assumption of homogeneity of variances was not met for the measures of P-inhibition and P-inhibition/set-shifting. We, therefore, used an alpha level of $p < .01$ when interpreting those results. Age was not controlled for since age corrected standard scores were used in the analyses.

Standardized residual scores

Hierarchical regression analyses included each of the more complex measures of executive functions as the dependent variable and the lower level variables as predictors. From these analyses, lower level variables that contributed uniquely to the dependent variable were included in standard regression analyses. The resulting standard residuals were then used in further analyses to represent the SR-inhibition, SR-inhibition/set-shifting and SR-set-shifting measures. Multicollinearity, linearity, and homoscedasticity were evaluated, and Kolomogorov-Smirnoff test of normality and casewise diagnosis were used to evaluate normality of standard residuals (SRs).

SR-inhibition

Since reading problems are associated with ADHD, we included both condition 1 and 2 as independent variables in the hierarchical regression analyses. Performance on these conditions explained 36.4% of the variance in condition 3. When exploring the unique contribution of each variable, the contribution of condition 2 was non-significant and only condition 1, which explained 36.3% of the variance in condition 3, was used as a predictor in the final analyses to generate SRs.

SR-inhibition/set-shifting

First we included the two primary summary conditions (condition 1 and 2) as predictors in two consecutive steps. Together, they explained 14.2% of the variance in condition 4. When exploring the unique contribution of each variable, only condition 1 contributed significantly by explaining 13.6% of the variance and was used as a predictor in the final analyses to generate SRs.

SR-set-shifting

To obtain a measure of set-shifting, we added condition 3 as a predictor of condition 4. Together, the three first conditions explained 35% of the variance. Only condition 3 contributed

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

Table 1. Hierarchical Regression ($N = 120$) Including Variables Predicting Inhibition and Set-shifting

Predictor variable(s)	Dependent variable	*beta*	*B*	R^2 *change*	*P*
	Inhibition				
Model 1					
Condition 1		.60	1.33	.36	<.001
Model 2					
Condition 1		.58	1.29	.00	<.001
Condition 2		.04	0.12		.682
	Inhibition/ set-shifting				
Model 1					
Condition 1		.37	1.41	.14	<.001
Model 2					
Condition 1		.32	1.22	.01	.002
Condition 2		.09	0.50		.385
	Set-shifting				
Model 1					
Condition 1		−.01	−0.05	.21	.910
Condition 2		.07	0.39		.445
Condition 3		.57	0.98		<.001

significantly with unique variance and explained 34.6% of the variance of condition 4. The resulting residuals were included in the final analyses to generate SRs. See Table 1 and 2 for more details about the regression analyses.

To examine differences between the groups, the standard residual from each regression analysis was included in separate ANCOVAs. Age was used as a covariate in all analyses. For significant results, follow-up ANCOVAs included IQ and working memory as covariates.

Significance level was set to 0.05 for all analyses, except for measures where assumptions of Equality of Covariance or Equality of Error Variance were violated (then the alpha level was reduced to 0.01).

Socio-demographic and Clinical Data

Statistically significant differences were observed between the ADHD group and control group in age, mean IQ and years of education, but not in sex distribution. A significantly higher proportion of individuals in the ADHD group than in the control group were without work, had difficulties related to reading and writing, alcohol and drugs, depression/anxiety, or had parents or siblings with ADHD. Only 11.9% of the ADHD group had received the diagnosis in childhood. Separate group-analyses were run between the two control samples, revealing no significant differences in IQ ($p = .097$), ASRS ($p = .567$), and WURS ($p = .767$) scores. See Table 3 for socio-demographic and clinical information and Table 4 for data on comorbidity. Different sample sizes in different conditions are due to missing data.

To examine whether the subsamples studied here ($n = 60 + 60$) were representative for the total sample studied in the parent project ($n = 572 + 895$), we compared the total WURS and the ASRS symptom scores for these groups. There were no statistically significant differences between these scores for either group (WURS ADHD, $p = .289$; ASRS ADHD, $p = .067$; WURS control, $p = .836$; ASRS control, $p = .983$). The samples on and without ADHD medication were compared on primary and contrast measures (including SR's), revealing no statistically significant group differences (condition 1, $p = .514$; condition 2, $p = .151$; condition 3, $p = .489$; condition 4, $p = .189$; P-inhibition, $p = .145$; P-inhibition/set-shifting, $p = .196$; P-set-shifting, $p = .447$; SR-inhibition, $p = .182$; SR-inhibition/set-shifting, $p = .108$; SR-set-shifting, $p = .267$).

Table 2. Standard Regression for Variables Predicting Inhibition and Set-shifting ($N = 120$)

Predictor variable	Dependent variable	*beta*	*B*	*P*
	Inhibition			
Condition 1		.60	1.33	<.001
	Inhibition/set-shifting			
Condition 1		.37	1.41	<.001
	Set-shifting			
Condition 3		.59	1.01	<.001

RESULTS

Primary Summary Conditions and Contrast/ Standardized Residual Scores

A factorial MANCOVA showed that the ADHD group obtained significantly lower scores than the control group on the four primary summary conditions ($F(4,114) = 5.55$; $p < .001$; Wilks' Lambda = 0.84; $\eta_p^2 = 0.16$). A Bonferroni adjusted *post hoc* test with an alpha level of 0.003 showed statistically significant group differences on condition 2 ($F(1,117) = 9.85$; $p = 0.002$; $\eta_p^2 = 0.078$) and condition 4, ($F(1,117) = 14.94$; $p < .001$; $\eta_p^2 = 0.113$). When running a separate univariate ANCOVA, including age, total IQ, and working memory as covariates, the result for condition 4 was still statistically significant ($F(1,112) = 13.27$; $p < .001$; $\eta_p^2 = 0.106$).

The results for the primary contrast measures were analyzed separately with ANOVAs, Bonferroni corrected for multiple comparisons (alpha level 0.017). The ADHD group obtained significantly lower scores than the control group on the P-set-shifting score ($F(1,118) = 8.57$, $p = 0.004$, $\eta_p^2 = 0.068$). This was also true after controlling for working memory and total IQ ($F(1,113) = 9.394$; $p = .003$; $\eta_p^2 = 0.077$).

ANCOVA with age as a covariate showed a statistically significant difference (Bonferroni corrected alpha level 0.003) between the groups on the SR-inhibition/set-shifting score ($F(1,117) = 11.449$; $p = .001$; $\eta_p^2 = 0.089$), with lower scores in the ADHD group. This result was still significant when including total IQ and working memory as covariates ($F(1,112) = 11.937$; $p = .001$; $\eta_p^2 = 0.096$).

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

Table 3. Socio-demographical and Clinical Data

	ADHD			Control			
	M/%	*S*	*N*[a]	*M*/%	*S*	*N*[a]	*P*
Age, years	34.4	9.9	60	29.0	6.9	60	.001
Males	48.3		60	38.3		60	.269
Education, years	12.6	2.4	60	15.1	2.5	60	<.001
Total IQ	110.1	13.6	57	114.8	9.6	60	<.05
WURS, mean score	56.3	18.5	52	17.9	13.1	57	<.001
ASRS, mean score	48.6	9.0	58	22.6	9.7	58	<.001
ASRS, inattention score	25.6	5.2	58	12.9	5.8	59	<.001
ASRS, hyperactivity score	23.1	5.7	59	9.7	4.8	58	<.001
No ADHD regarding to ASRS	10.3		58	91.4		58	<.001
[b]Inattentive type defined regarding to ASRS	25.9		58	6.9		58	.01
[b]Hyperactive type defined regarding to ASRS	1.7		58	0.0		58	.315
[b]Combined type defined regarding to ASRS	62.1		58	1.7		58	<.001
In work	33.3		57	79.1		43	<.001
[c]Prescribed medication (central stimulantia or other medication for ADHD)	67.3		52	0.0		60	<.001
Parents or siblings with ADHD	42.4		59	1.7		60	<.001
ADHD diagnosis received in childhood	11.9		59	0.0		60	<.05

[a]*N* varies due to missing data and reflects number of participants investigated for each variable.
[b]cut off were defined as 21 points or more on one or both subscales as described in Kessler et al. (2005).
[c]all participants were asked not to take medication for ADHD the day of testing.

ANCOVA with age as a covariate showed a statistically significant difference (Bonferroni corrected alpha level 0.003) between the groups on the SR-set-shifting score ($F(1,117) = 11.524$; $p = .001$; $\eta_p^2 = 0.090$). The result was still significant when IQ and working memory were included as covariates ($F(1,112) = 12.359$; $p = 0.001$; $\eta_p^2 = 0.099$). See Table 5 for more details about primary summary measures, primary contrast measures and residual analyses.

Additional Analyses

We performed additional analyses where we included sex as an independent variable in the MANCOVA and all ANCOVA analyses. There were no statistically significant effects of sex or sex-by-group interactions for any of the measures. Analyses with control for reading and writing problems (measured by a screening question that asked if

Table 4. Comorbidity

	ADHD		Control		
	%	*N*[a]	%	*N*[a]	*P*
Lifetime difficulties with reading and writing	43.3	60	8.3	60	<.001
Lifetime problems with alcohol	20.0	60	0.0	60	<.001
Lifetime problems with other drugs	26.7	60	1.7	60	<.001
Lifetime depression/anxiety	56.7	60	11.7	60	<.001
Lifetime bipolar disorder	5.1	59	0.0	60	.077
Current substance abuse/dependence	6.9	58	0.0	60	.164
Current depressive episode	16.9	59	3.3	60	.031
Current manic episode	0.0	59	0.0	60	ns
Current use of antidepressants	8.9	57	3.4	58	.223
Current use of mood-stabilizers	1.8	57	0.0	58	.307
Current use of benzodiazepines or other hypnotics	3.6	57	0.0	58	.146
Lifetime use of antidepressants	20.0	60			
Lifetime use of antipsychotics	5.0	60			
Lifetime use of mood-stabilizers	6.7	60			
Lifetime use of benzodiazepines	11.7	60			

[a]*N* varies due to missing data and reflects number of participants investigated for each variable.

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

Table 5. Performance on CWIT in the ADHD and Control group

	ADHD (N = 60)		Control (N = 60)				
	Mean	*SD*	*Mean*	*SD*	*F*	*P*	ηp^{2a}
Primary summary measures							
Condition 1	30.32	6.16	28.23	4.41	2.860	.093	.024
Condition 2	22.57	4.25	20.52	2.55	9.849	.002	.078
Condition 3	56.37	13.08	51.12	10.29	2.982	.087	.025
Condition 4	71.07	25.39	56.00	10.14	14.942	<.001	.113
Primary contrast measures							
P-inhibition	10.28	2.80	10.43	2.11	0.110	.741	.001
P-inhibition/set-shifting	8.55	3.26	9.75	2.37	5.309	.023	.043
P-set-shifting	8.73	2.79	10.18	2.64	8.568	.004	.068
Residual analyses							
SR-inhibition	0.13	1.13	−0.13	0.83	0.712	.400	.006
SR-inhibition/set-shifting	0.31	1.24	−0.31	0.51	11.449	.001	.089
SR-set-shifting	0.29	1.20	−0.29	0.63	11.524	.001	.090

Note. Age was used as a covariate in all analyses, except for the primary contrast measures.
[a]ηp^2 = partial eta squared.

the person had ever experienced problems with writing or reading) were still statistically significant. We also removed all participants in the control group who screened positive for ADHD and reran the analyses. Cutoff was defined as 21 points or more on the inattention or hyperactivity scale, or both, as described by Kessler et al. (2005). These additional analyses did not change the results.

DISCUSSION

Analyses of the CWIT primary summary conditions revealed a multivariate statistically significant difference between the ADHD and the control group, but no significant differences between the groups on the inhibition condition (condition 3) were found when each condition was examined separately. However, there were significant differences between the groups on the fourth condition and both the primary and SR contrast measures of set-shifting, even after controlling for working memory and IQ. Although the effect sizes for the whole range of set-shifting measures were low, the fact that the lowered scores of set-shifting were found regardless of how it was analyzed, strengthened the conclusion of a set-shifting difficulty in the ADHD group. ANCOVAs based on the US-normed standard scores from D-KEFS and the SR measures based on raw scores showed similar results, suggesting that the US-norms are applicable in a Norwegian sample of adults with ADHD.

The lack of significant group differences on measures of inhibition are in disagreement with results from a meta-analysis performed by Lansbergen, Kenemans, and van Engeland (2007) and the results from the UMASS study (Barkley et al., 2008), in which participants with ADHD showed impaired performance on the Stroop inhibition condition, even after controlling for basic conditions. However, in a meta-analysis by Schwartz and Verhaeghen (2008), the Stroop inhibition effect was not larger for individuals with ADHD than for normal controls.

The inconsistent results may partly be due to different methods used for calculating the inhibition effect. Several meta-analyses have used either the "Golden's method" or the "difference score" (Hervey, Epstein, & Curry, 2004; Homack & Riccio, 2004; van Mourik, Oosterlaan, & Sergeant, 2005). The difference score is calculated as the difference between the color naming and color word inhibition scores and was also used in the UMASS study. "Golden's Method" (Golden, 1978) is calculated by predicting the score on the color word inhibition condition from the scores on the basic conditions and then subtracting this score from the actual score on the color word inhibition condition. However, both methods have been criticized by Lansbergen et al. (2007) and Delis et al. (2001) for leading to incorrect estimates of the inhibition effect. Lansbergen et al. (2007) and Schwartz and Vaerhagen (2008), therefore, used a ratio score to calculate the inhibition measure, and Delis et al. (2001) constructed the contrast scores to standardize the difference between the variables in the D-KEFS. Although both used a ratio score to calculate the inhibition effect, the meta-analyses performed by Lansbergen et al. and Schwartz and Vaerhagen yielded different results. This may be explained by methodological differences: while Lansbergen et al. also included computerized Stroop tests, Schwartz and Vaerhagen only included the original Golden Stroop test. This example reveals how different tests of inhibition may measure different aspects of inhibition as well as related functions.

The fourth condition from the CWIT is a complex task, and this may at least partly explain why the ADHD group obtained significantly lower scores than the control group. This complexity probably reflects interplay between set-shifting and inhibition, and the test results thus represent more than just an additive effect. However, Lippa and Davis (2010) found that many patients actually showed better

https://doi.org/10.1017/S1355617712000355 Published online by Cambridge University Press

performance on the fourth condition than on the third condition, as was also reported in a study of individuals with schizophrenia (Savla et al., 2011). This shows that the fourth condition is not necessarily more difficult, and an alternative explanation may, therefore, be that the training effect from the former condition is reduced in the ADHD group. It is also possible that adults with ADHD have more problems with the type of shifting measured by the CWIT than other clinical groups. Kramer et al. (2007) suggest that the inconsistency in the literature concerning set-shifting may be attributed to the diversity in defining and measuring the concept. While some tests measure the subjects' ability to alter their sorting strategies when reinforcement contingencies change, other tasks require serial alternation between two different types of stimuli. They also suggest that it is likely that the different types of set-shifting tasks have different underlying neuroanatomical correlates. More research is needed to determine if it is a deficit in the specific executive function after considering its non-executive and other executive components, or the general complexity of the task that cause the group differences.

Limitations

Before generalizing the results from this study to other adult ADHD samples, some limitations should be taken into account.

The parent study has a naturalistic design and the participants were diagnosed by different clinicians. This may have yielded a more heterogeneous ADHD sample than in studies with more stringent inclusion criteria based on diagnostic information gathered by one clinician. Furthermore, the high non-response rate in the parent study may have led to a selection bias toward the more motivated participants, and the high IQ in both the ADHD group and the control group shows that there may have been a bias toward recruitment of the more well-functioning individuals. Caution is, therefore, necessary in generalizing the results of this study to the general population or other samples of adults with ADHD.

Only 11.9% of our adult ADHD patients received a formal diagnosis of ADHD during childhood. As the number of children diagnosed with ADHD in Norway has recently increased, the low percentage diagnosed in childhood in previous years probably reflects a low awareness of ADHD at the time when the participants were children.

There is a high prevalence of co-existing psychiatric conditions in ADHD samples (Sobanski et al., 2007). Other comorbid conditions may have influenced our results and the inclusion of clinical control groups, with for example anxiety or depression, might have provided more insight into the specificity of the neuropsychological deficits observed in the present study. We believe that the clinical ADHD group in the present study is representative for the clinical population of ADHD patients. This suggests that some of the participants were on medication for comorbid conditions at the time of participation and that some also met criteria for current substance abuse. Excluding those participants may have yielded a less representative group.

Kopp (2011) has argued that contrast measures are associated with a low reliability and may simply be a function of the average reliability of its two components and of the correlation between them (Crawford, Sutherland, & Garthwaite, 2008). For example, the D-KEFS defined inhibition/set-shifting minus inhibition contrast score had a test–retest reliability of −0.041 in the group aged 20–49 years, and a score of −0.107 in the age range 50–89. In this study, similar results obtained by using SR measures based on raw scores and the D-KEFS contrast scores indicate that the results add to the validity evidence base for the contrast scores. However, more studies of the reliability and validity of the D-KEFS contrast scores are called for.

Conclusions and Implications for Further Research

The present study showed difficulties related to set-shifting tasks in adults with ADHD. This result was strengthened by the fact that these problems were consistently observed regardless of how the data were analyzed. This kind of robustness is important when evaluating individuals with ADHD because impairment of only a single primary measure may disguise problems in other aspects of cognitive function.

Rommelse and Buitelaar (2008) argue that it is useful to make a distinction between primary and secondary EF difficulties for scientific and therapeutic reasons. They suggested that a clarification of the hierarchical origin of executive difficulties in patients with ADHD could help us better understand the nature of the pathology of the disorder and that intervention targets may differ when difficulties stem from the bottom (basic encoding and/or motor processes) instead of the top of the hierarchy (executive processes). The significant differences after controlling for covariates could indicate that adults with ADHD have specific problems with set-shifting, but more studies are needed to validate our findings. If such specific difficulties are found, this may help to explain some of the common symptoms reported by patients with ADHD in the clinic, such as the inability to shift efficiently from one mental activity to another.

The main contributions of the present study are the use of two different contrast measures to control for more basic functions and the inclusion of IQ and working memory function as covariates. Further studies should combine such measures of neuropsychological function with more detailed clinical information as well as biomarkers generated from brain imaging and genetics. These types of studies would contribute important knowledge about neurocognitive dysfunctions in ADHD and other neuropsychiatric disorders.

ACKNOWLEDGMENTS

The project has received financial support from The Research Council of Norway, The Western Norway Regional Health Authority and the K.G. Jebsen Foundation. The study was also supported by "The National Program for Integrated Clinical Specialist and PhD-training for Psychologists" in Norway by financial support to H.H. This program is a joint cooperation between the Universities of Bergen, Oslo, Tromsø, the Regional Heath Authorities, and the Norwegian

Psychological Association. The program is funded jointly by The Ministry of Education and Research and The Ministry of Health and Care Services. None of the authors have any conflicts of interest. We thank the participants, Johanne Telnes Instanes, Anne Halmøy, Margaretha Dramsdahl, Liv Heldal, Ragnhild Nordenborg, Lisa Vårdal, Vivica Næss, and the other members of the research group. We also thank Steinunn Adolfsdottir for the discussions concerning this study.

REFERENCES

Adolfsdottir, S., Sorensen, L., & Lundervold, A.J. (2008). The attention network test: A characteristic pattern of deficits in children with ADHD. *Behavioral and Brain Functions*, *4*, 9. doi:10.1186/1744-9081-4-9

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*(2), 71–82.

Barkley, R.A. (1997a). *ADHD and the nature of self-control*. New York: Guilford Press.

Barkley, R.A. (1997b). Attention-deficit/hyperactivity disorder, self-regulation, and time: Toward a more comprehensive theory. *Journal of Developmental and Behavioral Pediatrics*, *18*(4), 271–279.

Barkley, R.A. (1997c). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin*, *121*(1), 65–94.

Barkley, R.A. (2010). Differential diagnosis of adults with ADHD: The role of executive function and self-regulation. *The Journal of Clinical Psychiatry*, *71*(7), e17. doi:10.4088/JCP.9066tx1c

Barkley, R.A., Murphy, K.R., & Fischer, M. (2008). *ADHD in adults: What the science says*. New York: Guilford.

Boonstra, A.M., Kooij, J.J., Buitelaar, J.K., Oosterlaan, J., Sergeant, J.A., Heister, J.G., & Franke, B. (2008). An exploratory study of the relationship between four candidate genes and neurocognitive performance in adult ADHD. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics*, *147*(3), 397–402. doi:10.1002/ajmg.b.30595

Castellanos, F.X., Sonuga-Barke, E.J., Milham, M.P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences*, *10*(3), 117–123. doi:10.1016/j.tics.2006.01.011

Castellanos, F.X., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. [Review]. *Nature Reviews. Neuroscience*, *3*(8), 617–628. doi:10.1038/nrn896

Crawford, J.R., Sutherland, D., & Garthwaite, P.H. (2008). On the reliability and standard errors of measurement of contrast measures from the D-KEFS. *Journal of the International Neuropsychological Society*, *14*(6), 1069–1073. doi:10.1017/S1355617708081228

Delis, D.C., Kaplan, E., & Kramer, J.H. (2001). *Delis-Kaplan Executive Function System*. San Antonio, TX: The Psychological Corporation.

Denckla, M.B. (1996). A theory and model of executive function: A neuropsychological perspective. In G.R. Lyon & N.A. Krasnegor (Eds.), *Attention, Memory, and Executive Function* (pp. 263–277). Baltimore: Paul H. Brookes.

Faraone, S.V., & Biederman, J. (2005). What is the prevalence of adult ADHD? Results of a population screen of 966 adults. *Journal of Attention Disorders*, *9*(2), 384–391. doi:10.1177/1087054705281478

Gallagher, R., & Blader, J. (2001). The diagnosis and neuropsychological assessment of adult attention deficit/hyperactivity disorder. Scientific study and practical guidelines. *Annals of the New York Academy of Sciences*, *931*, 148–171.

Golden, C.J. (1978). *Stroop Color and Word Test: A manual for clinical and experimental uses*. Chicago: Skoelting.

Gronwall, D.M. (1977). Paced auditory serial-addition task: A measure of recovery from concussion. *Perceptual and Motor Skills*, *44*(2), 367–373.

Halleland, H., Lundervold, A.J., Halmoy, A., Haavik, J., & Johansson, S. (2009). Association between catechol O-methyltransferase (COMT) haplotypes and severity of hyperactivity symptoms in adults. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics*, *150B*(3), 403–410. doi:10.1002/ajmg.b.30831

Halmoy, A., Halleland, H., Dramsdahl, M., Bergsholm, P., Fasmer, O.B., & Haavik, J. (2010). Bipolar symptoms in adult attention-deficit/hyperactivity disorder: A cross-sectional study of 510 clinically diagnosed patients and 417 population-based controls. *Journal of Clinical Psychiatry*, *71*(1), 48–57. doi:10.4088/JCP.08m04722ora

Heiervang, E., Stormark, K.M., Lundervold, A.J., Heimann, M., Goodman, R., Posserud, M.B., … Gillberg, C. (2007). Psychiatric disorders in Norwegian 8- to 10-year-olds: An epidemiological survey of prevalence, risk factors, and service use. *Journal of the American Academy of Child and Adolescent Psychiatry*, *46*(4), 438–447. doi:10.1097/chi.0b013e31803062bf

Hervey, A.S., Epstein, J.N., & Curry, J.F. (2004). Neuropsychology of adults with attention-deficit/hyperactivity disorder: A meta-analytic review. *Neuropsychology*, *18*(3), 485–503. doi:10.1037/0894-4105.18.3.485

Homack, S., & Riccio, C.A. (2004). A meta-analysis of the sensitivity and specificity of the Stroop Color and Word Test with children. *Archives of Clinical Neuropsychology*, *19*(6), 725–743. doi:10.1016/j.acn.2003.09.003

Johansson, S., Halleland, H., Halmoy, A., Jacobsen, K.K., Landaas, E.T., Dramsdahl, M., … Haavik, J. (2008). Genetic analyses of dopamine related genes in adult ADHD patients suggest an association with the DRD5-microsatellite repeat, but not with DRD4 or SLC6A3 VNTRs. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics*, *147B*(8), 1470–1475. doi:10.1002/ajmg.b.30662

Kessler, R.C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., … Walters, E.E. (2005). The World Health Organization Adult ADHD Self-Report Scale (ASRS): A short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256.

Kopp, B. (2011). Neuropsychologists must keep their eyes on the reliability of difference measures. *Journal of the International Neuropsychological Society*, 1–2. doi:10.1017/S1355617711000361

Kramer, J.H., Quitania, L., Dean, D., Neuhaus, J., Rosen, H.J., Halabi, C., … Miller, B.L. (2007). Magnetic resonance imaging correlates of set shifting. *Journal of the International Neuropsychological Society*, *13*(3), 386–392. doi:10.1017/S1355617707070567

Lansbergen, M.M., Kenemans, J.L., & van Engeland, H. (2007). Stroop interference and attention-deficit/hyperactivity disorder: A review and meta-analysis. *Neuropsychology*, *21*(2), 251–262. doi:10.1037/0894-4105.21.2.251

Lara, C., Fayyad, J., de Graaf, R., Kessler, R.C., Aguilar-Gaxiola, S., Angermeyer, M., … Sampson, N. (2009). Childhood predictors of adult attention-deficit/hyperactivity disorder: Results from the World Health Organization World Mental Health Survey

Initiative. *Biological Psychiatry*, *65*(1), 46–54. doi:10.1016/j.biopsych.2008.10.005

Lippa, S.M., & Davis, R.N. (2010). Inhibition/switching is not necessarily harder than inhibition: An analysis of the D-KEFS color-word interference test. *Archives of Clinical Neuropsychology*, *25*(2), 146–152. doi:10.1093/arclin/acq001

Lundervold, A.J., Adolfsdottir, S., Halleland, H., Halmoy, A., Plessen, K., & Haavik, J. (2011). Attention network test in adults with ADHD—the impact of affective fluctuations. *Behavioral and Brain Functctions*, *7*, 27. doi:10.1186/1744-9081-7-27

Mick, E., Faraone, S.V., & Biederman, J. (2004). Age-dependent expression of attention-deficit/hyperactivity disorder symptoms. [Review]. *Psychiatric Clinics of North America*, *27*(2), 215–224. doi:10.1016/j.psc.2004.01.003

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. doi:10.1006/cogp.1999.0734

Nigg, J.T. (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin*, *127*(5), 571–598.

Pa, J., Possin, K.L., Wilson, S.M., Quitania, L.C., Kramer, J.H., Boxer, A.L., … Johnson, J.K. (2010). Gray matter correlates of set-shifting among neurodegenerative disease, mild cognitive impairment, and healthy older adults. *Journal of the International Neuropsychological Society*, *16*(4), 640–650. doi:10.1017/S1355617710000408

Piek, J.P., Dyck, M.J., Francis, M., & Conwell, A. (2007). Working memory, processing speed, and set-shifting in children with developmental coordination disorder and attention-deficit-hyperactivity disorder. *Developmental medicine and child neurology*, *49*(9), 678–683. doi:10.1111/j.1469-8749.2007.00678.x

Rasmussen, P., & Gillberg, C. (2000). Natural outcome of ADHD with developmental coordination disorder at age 22 years: A controlled, longitudinal, community-based study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*(11), 1424–1431. doi:10.1097/00004583-200011000-00017

Ravizza, S.M., & Ciranni, M.A. (2002). Contributions of the prefrontal cortex and basal ganglia to set shifting. *Journal of Cognitive Neuroscience*, *14*(3), 472–483. doi:10.1162/089892902317361985

Rohlf, H., Jucksch, V., Gawrilow, C., Huss, M., Hein, J., Lehmkuhl, U., & Salbach-Andrae, H. (2012). Set shifting and working memory in adults with attention-deficit/hyperactivity disorder. *Journal of Neural Transmission*, *119*(1), 95–106. doi:10.1007/s00702-011-0660-3

Rommelse, N.J., & Buitelaar, J.K. (2008). Executive functioning in attention-deficit–hyperactivity disorder – Crucial or trivial? *European Psychiatric Review*, (2), 17–20.

Savla, G.N., Twamley, E.W., Thompson, W.K., Delis, D.C., Jeste, D.V., & Palmer, B.W. (2011). Evaluation of specific executive functioning skills and the processes underlying executive control in schizophrenia. *Journal of the International Neuropsychological Society*, *17*(1), 14–23. doi:10.1017/S1355617710001177

Schwartz, K., & Verhaeghen, P. (2008). ADHD and Stroop interference from age 9 to age 41 years: A meta-analysis of developmental effects. *Psychological Medicine*, *38*(11), 1607–1616. doi:10.1017/S003329170700267X

Sheehan, D.V., Lecrubier, Y., Sheehan, K.H., Amorim, P., Janavs, J., Weiller, E., … Dunbar, G.C. (1998). The Mini-International Neuropsychiatric Interview (M.I.N.I.): The development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. *Journal of Clinical Psychiatry*, *59*(Suppl 20), 22–33; quiz, 34–57.

Sobanski, E., Bruggemann, D., Alm, B., Kern, S., Deschner, M., Schubert, T., … Rietschel, M. (2007). Psychiatric comorbidity and functional impairment in a clinically referred sample of adults with attention-deficit/hyperactivity disorder (ADHD). *European Archives of Psychiatry and Clinical Neuroscience*, *257*(7), 371–377. doi:10.1007/s00406-007-0712-8

Tillman, C.M., Bohlin, G., Sorensen, L., & Lundervold, A.J. (2009). Intellectual deficits in children with ADHD beyond central executive and non-executive functions. *Archives of Clinical Neuropsychology*, *24*(8), 769–782. doi:10.1093/arclin/acp075

van Mourik, R., Oosterlaan, J., & Sergeant, J.A. (2005). The Stroop revisited: A meta-analysis of interference control in AD/HD. *Journal of Child Psychology and Psychiatry*, *46*(2), 150–165. doi:10.1111/j.1469-7610.2004.00345.x

Ward, M.F., Wender, P.H., & Reimherr, F.W. (1993). The Wender Utah Rating Scale: An aid in the retrospective diagnosis of childhood attention deficit hyperactivity disorder. *American Journal of Psychiatry*, *150*(6), 885–890.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of intelligence. WASI. Manual*. San Antonio, TX: The Psychological Corporation.

Willcutt, E.G., Doyle, A.E., Nigg, J.T., Faraone, S.V., & Pennington, B.F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: a meta-analytic review. *Biological Psychiatry*, *57*(11), 1336–1346. doi:10.1016/j.biopsych.2005.02.006

Wodka, E.L., Loftis, C., Mostofsky, S.H., Prahme, C., Larson, J.C., Denckla, M.B., & Mahone, E.M. (2008). Prediction of ADHD in boys and girls using the D-KEFS. *Archives of Clinical Neuropsychology*, *23*(3), 283–293. doi:10.1016/j.acn.2007.12.004