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Set shifting and working memory in adults with attention-deficit/hyperactivity disorder

Helena Rohlf · Viola Jucksch · Caterina Gawrilow · Michael Huss · Jakob Hein · Ulrike Lehmkuhl · Harriet Salbach-Andrae

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Abstract Compared to the high number of studies that investigated executive functions (EF) in children with attention-deficit/hyperactivity disorder (ADHD), a little is known about the EF performance of adults with ADHD. This study compared 37 adults with ADHD ($ADHD_{total}$) and 32 control participants who were equivalent in age, intelligence quotient (IQ), sex, and years of education, in two domains of EF—set shifting and working memory. Additionally, the $ADHD_{total}$ group was subdivided into two subgroups: ADHD patients without comorbidity ($ADHD^{-}$, $n = 19$) and patients with at least one comorbid disorder ($ADHD^{+}$, $n = 18$). Participants fulfilled two measures for set shifting (i.e., the trail making test, TMT and a computerized card sorting test, CKV) and one measure for working memory (i.e., digit span test, DS). Compared to the control group the $ADHD_{total}$ group displayed deficits in set shifting and working memory. The differences between the groups were of medium-to-large effect size (TMT: $d = 0.48$; DS: $d = 0.51$; CKV: $d = 0.74$). The subgroup comparison of the $ADHD^{+}$ group and the $ADHD^{-}$ group revealed a poorer performance in general information processing speed for the $ADHD^{+}$ group. With regard to set shifting and working memory, no significant differences could be found between the two subgroups. These results suggest that the deficits of the $ADHD_{total}$ group are attributable to ADHD rather than to comorbidity. An influence of comorbidity, however, could not be completely ruled out as there was a trend of a poorer performance in the $ADHD^{+}$ group on some of the outcome measures.

Keywords Adult ADHD · Neuropsychology · Executive functions · Comorbidity

H. Rohlf (✉) · V. Jucksch · U. Lehmkuhl · H. Salbach-Andrae
Department of Child and Adolescent Psychiatry, Psychosomatics and Psychotherapy, Charité-Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany
e-mail: helena.rohlf@gmx.de

C. Gawrilow
Center for Research on Individual Development and Adaptive Education of Children at Risk (IDeA), German Institute for International Educational Research, University of Frankfurt, Mertonstr. 17, 60325 Frankfurt, Germany

M. Huss
Department for Child and Adolescent Psychiatry and Psychotherapy, Johannes Gutenberg-University Mainz, Langenbeckstraße 1, 55131 Mainz, Germany

J. Hein
Department of Psychiatry and Psychotherapy, Charité-Universitätsmedizin Berlin, Charitéplatz 1, 10117 Berlin, Germany

Introduction

ADHD is one of the most frequently diagnosed disorders in childhood with a prevalence of 5–10% (Biederman 2005). In 50–60% of the cases, ADHD symptoms continue into adulthood (Barkley et al. 2002; Mannuzza et al. 1993; Weiss et al. 1985) with a reported prevalence among adults of 1–7% (Fayyad et al. 2007; Kessler et al. 2006; Simon et al. 2009). ADHD is characterized by three core symptoms: impulsivity, hyperactivity, and inattention; the latter symptom seems to be the most persistent one in adulthood (Mick et al. 2004).

Neuropsychological research on ADHD focuses on the assessment of executive functions (EF) because symptoms of ADHD are supposed to be caused by a weakness of a specific domain of EF or a general deficit in EF by some authors (Barkley 1997; Brown 2008; Castellanos and Tannock 2002). The term EF refers to a set of higher order cognitive functions, necessary to "maintain an appropriate problem solving set for attainment of a future goal" (Welsh and Pennington 1988). EF are commonly grouped into three domains: (1) inhibition, (2) mental set shifting, and (3) working memory (Miyake et al. 2000). The number of studies that investigated the associations between these domains and adult ADHD is far higher for inhibition than for set shifting and working memory (i.e., Epstein et al. 2001; Johnson et al. 2001; Johnson et al. 2010; Murphy 2002b; Ossmann and Mulligan 2003; Wodushek and Neumann 2003). Therefore, we focused on these latter two EF domains in our study. Set shifting refers to the ability to switch flexibly back and forth between mental sets or multiple tasks (Monsell 1996). Working memory is thought to be a temporally limited storage mechanism in which task-relevant information is monitored and manipulated in order to enable complex behavior (Ullsperger and von Cramon 2006).

In children with ADHD, numerous studies reported deficits of medium effect size for both domains (i.e., Brocki et al. 2008; Corbett et al. 2009; Oades and Christiansen 2008; Romine et al. 2004; Willcutt et al. 2005). Only a few studies have investigated set shifting and working memory in adults with ADHD so far; and these studies have generated inconsistent results (Boonstra et al. 2005; Engelhardt et al. 2008; Gropper and Tannock 2009; Johnson et al. 2001; Marchetta et al. 2008; Marx et al. 2010; Mueller et al. 2007; Murphy et al. 2001; Murphy 2002a; Rapport et al. 2001; Schoechlin and Engel 2005; Schweitzer et al. 2006; Seidman et al. 1997; Stavro et al. 2007; Walker et al. 2000).

With regard to set shifting tasks (i.e., the trail making test, TMT; Reitan 1986b or the Wisconsin card sorting test, WCST; Grant and Berg 1948) some researchers have found that adults with ADHD perform poorer than healthy control participants (Johnson et al. 2001; Marchetta et al. 2008; Mueller et al. 2007; Murphy 2002a; Seidman et al. 1997), while other researchers failed to find differences between adults with ADHD and healthy control participants in the WCST (Rapport et al. 2001; Stavro et al. 2007) or the TMT (Walker et al. 2000). The studies that assessed working memory in adults with ADHD (i.e., as measured with the digit span backward which is a subtest of the Wechsler adult intelligence scale-third edition, WAIS-III; Wechsler 1997) also displayed heterogeneous results. Some researchers found that adults with ADHD perform poorly compared to healthy control participants in working memory tasks (Gropper and Tannock 2009; Walker et al. 2000). At the same time, other researchers could not replicate these differences between adults with and without ADHD after controlling for the influence of IQ (Murphy et al. 2001); or they could support a poorer performance only for the predominantly inattentive type of ADHD, but not for the combined type (Schweitzer et al. 2006).

These inconsistencies in research findings may partly be due to the methodological problems of the previous studies. First, most studies failed to control the influence of subtypes of ADHD. Several studies found differences in neuropsychological functioning between subtypes of ADHD in adulthood with not all three subtypes displaying deficits in EF (Gansler et al. 1998; Schweitzer et al. 2006; Tucha et al. 2008). Although other studies have not found any respective differences (Murphy et al. 2001), it is possible that the inclusion of all three subtypes of ADHD in the previous studies investigating EF in adults with ADHD contributes to the inconsistent results. To rule out this potentially confounding effect, only the combined type of ADHD was included in the present study.

Second, when examining set shifting and working memory, it needs to be considered that task performance for both domains can be influenced by other neuropsychological functions, such as attention capacity and information processing speed. Deficits in these functions have been reported for adults with ADHD (Boonstra et al. 2005; Gansler et al. 1998; Mueller et al. 2007; Murphy 2002a). Therefore, the performance in neuropsychological functions other than set shifting and working memory needs to be controlled for. Only a few of the previous studies applied respective control measures (Marchetta et al. 2008; Stavro et al. 2007). To consider this issue, we used dependent measures in the present study that assess the function of the EF domains set shifting and working memory isolated from other neuropsychological functions.

Third, it has to be considered that ADHD often co-occurs with other psychiatric disorders including mood disorders, antisocial personality disorder, and substance use disorder. Since many of these comorbidities appear to be related to EF deficits (Baudic et al. 2004; Croft et al. 2001; Rupp et al. 2006; Smith et al. 2006), they might influence the performance on set shifting and working memory tasks. Therefore, it is essential to control for the possibly confounding factor comorbidity to determine whether ADHD is actually associated with deficits in set shifting and working memory, or whether deficits are rather attributable to the presence of a comorbid psychiatric disorder. Only a few of the previous studies have considered this issue by controlling the impact of comorbidity (i.e., Marchetta et al. 2008; Walker et al. 2000). Therefore, in this study, the sample of patients with ADHD ($ADHD_{total}$) was subdivided into a group of patients with ADHD, as well as comorbid disorders ($ADHD^{+}$) on the one hand, and a group of ADHD patients without comorbid disorders ($ADHD^{-}$) on the other hand. A subgroup comparison was conducted assuming that if the $ADHD^{+}$ group did not perform poorer than the $ADHD^{-}$ group, differences in the performance between the $ADHD_{total}$ group and healthy control participants would be attributable to the presence of ADHD.

The primary aim of the present study was to compare the performance of adults with ADHD (combined type only) and adults without ADHD in the EF domains set shifting and working memory. The second aim was to investigate if potential deficits are related to the presence of ADHD or if they can rather be explained as an effect of additional psychiatric disorders that patients are suffering from. Based on the previous studies, we hypothesized that adults with ADHD would perform poorly compared to healthy control participants on set shifting and working memory tasks. Furthermore, we hypothesized no differences in the performance of ADHD patients with and without comorbidity.

Material and method

Participants

In total, 69 adult participants were included in the present study ($ADHD_{total}$, $n = 37$, healthy control group, $n = 32$). Their age ranged between 18 and 32 years ($M = 22.02$, SD = 2.97). Participants younger than 18 years of age, those with IQ values below 85, and those with neurological diseases or patients suffering from a severe head injury in the past were excluded from the study. Additional exclusion criteria in the control group were a history of psychiatric illness and the use of psychotropic substances, such as alcohol, drugs or medication during the week before the measurement, as this could influence task performance. The study was approved by the responsible local ethics committee. All patients and control subjects signed consent forms before participation in the study. Each subject received 20 Euro for participating. The $ADHD_{total}$ group and the control group did not differ significantly according to education, age, sex, and IQ. The two subgroups $ADHD^{+}$ and $ADHD^{-}$ showed no significant differences according to IQ, sex, and education, but the $ADHD^{+}$ group was significantly older than the $ADHD^{-}$ group. Demographic characteristics of all groups are presented in Table 1.

Patients were recruited from the Department of Child and Adolescent Psychiatry, Psychosomatic Medicine and Psychotherapy, Charité-Universitätsmedizin Berlin, where they had either received treatment during their childhood or were currently receiving treatment due to an ADHD diagnosis according to DSM-IV (American Psychiatric Association; APA 1994) as their primary diagnosis ($n = 33$). Furthermore, patients were derived from the outpatient facility for adults with ADHD at the Department of Psychiatry and Psychotherapy, Charité-Universitätsmedizin Berlin ($n = 4$). Control participants were recruited by public announcements ($n = 16$) and by a notice posted in an evening school for adult students ($n = 16$).

All participants in the groups of $ADHD^{+}$ and $ADHD^{-}$ met the DSM-IV criteria for ADHD combined type. Patients who met either the criteria for the predominantly hyperactive/impulsive type or the predominantly inattentive type but not the combined type were excluded from the study. Four of the patients were currently receiving treatment with methylphenidate. These patients were asked to discontinue this treatment 2 weeks prior to their participation in the study to ensure a complete medication washout. None of the patients received medication with atomoxetine. One patient was medicated with an antidepressant due to a comorbid mood disorder. This might have had an influence on task performance, but as it was a female patient we decided to include her given the already little number of female patients in this study.

The $ADHD^{-}$ group consisted of participants who currently displayed no other psychiatric disorders than ADHD. All patients included in the $ADHD^{+}$ group met DSM-IV criteria for at least one comorbid psychiatric disorder at the time of their participation. Twelve patients were diagnosed with one additional Axis-I disorder or personality disorder, the remaining six patients suffered from two or three comorbidities. Comorbid diagnoses of the $ADHD^{+}$ group are summarized in Table 2.

Diagnostic procedure

A diagnostic assessment consisting of standardized psychometrical scales was conducted with all participants

Table 1 Characteristics of the sample

	Controls ($n = 32$)	$ADHD_{total}$ ($n = 37$)	t	df	p	$ADHD^{+}$ ($n = 18$)	$ADHD^{-}$ ($n = 19$)	t	df	p
Age (M, SD)	22.45 (2.96)	21.66 (2.98)	1.09	66	n.s.	22.79 (3.53)	20.59 (1.89)	2.38	66	0.023
Sex (male/female)	30/2	35/2	−0.02	66	n.s.	19/1	18/1	−0.48	66	n.s.
IQ (M, SD)	97.56 (8.57)	98.86 (11.80)	−0.59	66	n.s.	98.83 (10.34)	98.89 (13.32)	0.02	66	n.s.
Education in years (M, SD)	11.19 (1.55)	11.03 (1.99)	0.74	66	n.s.	11.00 (2.19)	11.05 (1.84)	0.08	66	n.s.

Table 2 Distribution of psychopathology other than ADHD in the $ADHD^+$ group

DSM-IV disorder	$ADHD^+$ ($n = 18$)
Mood disorder	6
Anxiety disorder	4
Substance-related disorders	7
Alcohol abuse	1
Alcohol dependence	2
Cannabis abuse	1
Cannabis dependence	3
Antisocial personality disorder	4
Schizoid personality disorder	2
Paranoid personality disorder	2
Narcissistic personality disorder	1
Avoidant personality disorder	1

individually by a professional examiner. This assessment included the German version self-report form of the Conner's adult ADHD rating scale (CAARS; Conners et al. 1999) and the ADHD-diagnostic checklist (ADHS-Diagnostische Checkliste, ADHS-DC; Rösler et al. 2008) to assess the presence of DSM-IV criteria of ADHD. The ADHS-DC is an expert rating scale that provides diagnoses of ADHD according to ICD-10 (World Health Organization; WHO 1991), and DSM-IV. Patients' and control participants' sum scores for the CAARS' scales inattentive symptoms and hyperactive/impulsive symptoms and the number of fulfilled DSM-IV ADHD criteria for the dimensions inattention and hyperactivity/impulsiveness as measured with the ADHS-DC are presented in Table 3.

The German version of the structured clinical interview for DSM–IV diagnosis (Wittchen et al. 1997) was applied to diagnose comorbid Axis-I disorders and personality disorders. IQ was assessed using the short form of the CFT-20-R (Weiß 2006).

Neuropsychological tasks

TMT

The TMT is a subtest of the Halstead-Reitan battery (Reitan 1986a). It consists of two parts: TMT Part A and TMT Part B. TMT Part A requires participants to connect, as quickly as possible, numbers from 1 to 25 that are randomly placed on a sheet of paper. In TMT Part B, participants are asked to connect, again as quickly as possible, numbers from 1 to 12 and letters from A to L in ascending order while alternating between numbers and letters (i.e., 1-A-2-B-3-C etc.). TMT Part A measures visual scanning, psychomotor speed, and information processing speed. TMT Part B additionally requires the ability to shift flexibly between two mental sets. Part B is therefore often used to measure set shifting (i.e., Bonilha et al. 2008; Kim et al. 2007; Klemm et al. 2006; Martel et al. 2007). To isolate the ability to shift between mental sets from other neuropsychological functions (i.e., information processing speed) we used the ratio of time required to complete TMT Part B and TMT Part A (i.e., the TMT shifting score) as the dependent measure. The TMT shifting score represents the performance in Part B corrected for the performance in Part A.

CKV

The CKV (Computergestütztes Kartensortierverfahren/computerized card sorting test; Drühe-Wienholt and Wienholt 2004) is a modified and computerized version of the WCST (Grant and Berg 1948). The WCST is one of the most commonly used tests for EF (i.e., Gallagher et al.

Table 3 CAARS sum scores and number of fulfilled ADHD criteria of patients and control participants

	Controls ($n = 32$) *M* (SD)	$ADHD_{total}$ ($n = 37$) *M* (SD)	*t*	*df*	*p*	$ADHD^-$ ($n = 19$) *M* (SD)	$ADHD^+$ ($n = 18$) *M* (SD)	*t*	*df*	*p*
CAARS										
Inattentive symptoms	4.72 (2.53)	11.19 (5.37)	−6.53	66	0.000	10.11 (5.01)	12.33 (5.65)	−1.27	66	0.21
Hyperactive/ impulsive symptoms	4.69 (3.25)	10.54 (4.34)	−6.15	66	0.000	10.53 (4.29)	10.56 (4.72)	−0.02	66	0.98
Total score	9.41 (5.10)	21.73 (8.36)	−7.50	66	0.000	20.63 (7.87)	22.89 (8.92)	−0.82	66	0.42
ADHS-DC										
Inattention	2.75 (1.74)	7.81 (1.23)	−13.55	66	0.000	7.79 (1.40)	7.83 (1.20)	−0.10	66	0.92
Hyperactivity/impulsiveness	2.41 (1.67)	7.78 (1.06)	−15.75	66	0.000	7.89 (1.10)	7.76 (1.03)	0.65	66	0.52
Total number	5.16 (2.76)	15.59 (1.79)	−18.33	66	0.000	15.68 (1.89)	15.50 (1.72)	0.31	66	0.76

2003; Klemm et al. 2006; Marazziti et al. 2008; Martel et al. 2007; Roca et al. 2010). It assesses the ability to sustain attention and to shift between cognitive sets in response to the changing rules. In this test, participants are asked to sort cards according to the color, shape, or a number of stimuli on the cards. The rule for sorting the cards changes during the test without notification. The correct rule has to be deduced from the computers' feedback, i.e., "incorrect" or "correct", given for each trial. Two variables of the CKV were chosen for the present study as measures for set shifting: The percent perseveration score and concept perseverations. Both variables indicate the participants' tendency to perseverate on a strategy despite the feedback "incorrect". The perseveration score indicates the proportion of perseverative errors relative to the number of total errors. The variable concept perseveration indicates that a participant made three or more consecutive sorts to one of the incorrect categories. Concept perseverations include at least two perseveration errors and therefore assess more severe perseveration tendencies when compared to the variable perseveration score.

WAIS digit span (DS)

The DS is a subtest of the Wechsler adult intelligence scale (WAIS; German version: Wechsler Intelligenztest für Erwachsene; von Aster et al. 2006) and is often used to measure working memory (i.e., Koenigs et al. 2009; Liepelt et al. 2008; Mueller et al. 2000; Rapeli et al. 2006; Samuelson et al. 2006). The test involves two subtests: DS forward (DSF) and DS backward (DSB). In both subtests, participants are required to repeat a series of digits read aloud by the experimenter. The difficulty increases by the presentation of increasingly longer series. Participants are given two trials of each span length. In DSF, these series have to be repeated in the order they were presented by the experimenter. This subtest is a measure for simple verbal memory and the attention span. In the DSB, the series have to be repeated backwards. This manipulation additionally requires working memory. The measure for working memory was computed according to the instruction in the German version of the WAIS, i.e., the difference between the highest number of correctly repeated digits in the forward condition and the backward condition (DSF–DSB). This calculation allows the assessment of working memory isolated from other neuropsychological functions.

Statistical analysis

The data were analyzed using SPSS version 15. To examine the relationship between tasks, Pearson product-moment correlations were computed. For the analyses of group differences, we performed univariate analyses of variance (ANOVA) with specified independent contrasts for following planned comparisons: (1) comparison of the $ADHD_{total}$ group and the control group, and (2) comparison of the subgroups $ADHD^{+}$ and $ADHD^{-}$. We additionally compared both subgroups with the control group using *t* tests for independent samples. These comparisons add further information about the influence of comorbidity, but they allow only a limited interpretation because they partly detect the same information as the ANOVA. Therefore, the results are only interpreted regarding the effect sizes, not the significances. Prior to the analysis, all demographic variables and outcome measures were checked for violations of assumptions associated with univariate tests. We found that not all variables met the assumption of a normal distribution. As a non-normal distribution is negligible when sample sizes are large enough ($n_1 > 30$ and $n_2 > 30$), we decided not to use a nonparametric test for the comparison of the $ADHD_{total}$ group and the control group. For the subgroup comparison, we additionally employed the nonparametric Mann–Whitney-*U* test for all variables with a non-normal distribution (age, IQ, TMT shifting score, perseveration score, and concept perseverations) due to the small sample size of the groups $ADHD^{+}$ and $ADHD^{-}$. Since results from the Mann–Whitney-*U* test were no different than the ANOVA findings, the results of the ANOVA are presented here. The subgroup difference in the age was controlled by a subsequent analysis of covariance (ANCOVA). Significance level was set at $p = 0.05$. For all group differences, we computed Cohen's *d* as a measure of the effect size. Following Cohen's (1988) guidelines, we classified effect sizes as small ($d = 0.2$), medium ($d = 0.5$), and large effects ($d = 0.8$).

Results

Correlation between variables

As shown in Table 4 high correlations were found between variables within tasks. Low correlations were found regarding the measures for cognitive flexibility and working memory, suggesting that these measures were independent of one another. A significant but relatively low correlation was found between the CKV concept perseverations and the TMT shifting score. The correlation between the CKV perseveration score and the TMT shifting score was not significant.

Comparison of patient group and control group

The mean scores and the standard deviations of all outcome measures according to the control group, the $ADHD_{total}$

Table 4 Correlations between the variables of the TMT, CKV, and WAIS DS

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. TMT Part A (s)	–	0.21	−0.49**	0.08	0.14	0.16	0.07	0.13	−0.06	0.21
2. TMT Part B (s)		–	0.71**	0.33**	0.40**	0.32**	0.39**	−0.05	−0.09	0.05
3. TMT shifting score (s)			–	0.16	0.17	0.12	0.26*	−0.14	−0.11	−0.03
4. Total errors				–	0.92**	0.82**	0.86**	−0.04	−0.04	0.00
5. Perseveration errors					–	0.88**	0.89**	0.03	0.08	−0.05
6. Perseveration score						–	0.85**	0.05	−0.04	0.11
7. Concept perseverations							–	−0.006	−0.00	0.00
8. DSF								–	0.57**	0.49**
9. DSB									–	−0.46**
10. DSF–DSB										–

* $p < 0.05$

** $p < 0.01$

Table 5 Mean values and standard deviations of test performances of the control group and the groups $ADHD_{total}$, $ADHD^{-}$ and $ADHD^{+}$

	$ADHD_{total}$ ($n = 37$) *M* (SD)	Controls ($n = 32$) *M* (SD)	$ADHD^{-}$ ($n = 19$) *M* (SD)	$ADHD^{+}$ ($n = 18$) *M* (SD)
TMT				
TMT Part A (s)	31.06 (7.88)	30.33 (9.94)	28.02 (6.73)	34.27 (7.89)
TMT Part B (s)	82.32 (29.36)	67.41 (17.99)	82.05 (33.66)	82.61 (25.01)
TMT shifting score (s)	2.86 (1.44)	2.33 (0.63)	3.16 (1.77)	2.53 (0.922)
CKV				
Total errors	20.29 (13.44)	14.06 (5.35)	19.32 (14.06)	21.33 (13.07)
Perseveration errors	6.14 (9.06)	1.88 (2.03)	5.89 (8.33)	6.39 (10.00)
Perseveration score	21.03 (16.26)	11.05 (9.76)	20.61 (16.57)	21.48 (16.41)
Concept perseverations	1.05 (1.63)	0.31 (0.47)	1.12 (1.85)	1.00 (1.41)
WAIS DS				
DSF	5.97 (1.07)	6.19 (1.03)	5.58 (1.06)	6.28 (1.02)
DSB	4.41 (0.93)	5.13 (1.04)	4.16 (0.602)	4.67 (1.14)
DSF–DSB	1.54 (0.93)	1.06 (0.95)	1.53 (0.91)	1.56 (0.98)

s seconds

group, and the subgroups $ADHD^{+}$ and $ADHD^{-}$ are summarized in Table 5.

Set shifting

We found that based on the TMT, the patient group performed significantly slower on the TMT Part B, ($t = -2.58$, $df = 66$, $p = 0.012$, $d = 0.48$), and had a significantly higher shifting score than the control group ($t = -1.98$, $df = 66$, $p = 0.05$, $d = 0.61$). No group differences were found on the TMT Part A ($t = -0.34$, $df = 66$, $p = 0.736$, $d = 0.08$). With regard to the CKV, the contrast test displayed significant differences between the two groups for all variables of the task with a poorer performance of the patient group. The analyses of effect sizes revealed medium to large effects (total errors: $t = -2.59$, $df = 66$, $p = 0.012$, $d = 0.65$; perseverations errors: $t = -2.78$, $df = 66$, $p = 0.008$, $d = 0.65$; perseveration score: $t = -3.03$, $df = 66$, $p = 0.003$, $d = 0.74$; concept perseverations: $t = -2.64$, $df = 66$, $p = 0.012$, $d = 0.61$).

Working memory

With respect to the WAIS DS, no significant group differences were found on the DSF ($t = 0.85$, $df = 66$, $p = 0.40$, $d = 0.20$). However, the ADHD group performed significantly poorer on the DSB than the control group ($t = 3.04$, $df = 66$, $p = 0.003$, $d = 0.72$) and reached a significantly higher score on the outcome measure for working memory, the difference between the scores on the DSF and the DSB ($t = -2.11$, $df = 66$, $p = 0.039$, $d = 0.51$).

Subgroup comparison of patients with and without comorbidity

The ANCOVA revealed a significant influence of age only for the CKV variable perseveration score. Therefore, for this variable the results of the ANCOVA are presented here.

Set shifting

The comparison between the subgroups ADHD$^+$ and ADHD$^-$ showed a significant group difference in the average total time for completing the TMT Part A ($t = -2.59$, $df = 66$, $p = 0.023$, $d = 0.57$). ADHD$^+$ participants performed slower than ADHD$^-$ participants. However, no significant group difference was found on the TMT Part B ($t = -0.57$, $df = 66$, $p = 0.95$, $d = 0.57$) and the TMT shifting score ($t = 1.36$, $df = 66$, $p = 0.18$, $d = 0.43$). According to the measures of the CKV, the contrast test revealed no significant group differences between participants with and without comorbidity (total errors: $t = -0.45$, $df = 66$, $p = 0.64$, $d = 0.15$; perseverations errors: $t = -0.16$, $df = 66$, $p = 0.87$, $d = 0.05$; perseveration score: $t = -0.16$, $df = 66$, $p = 0.31$, $d = 0.02$ concept perseverations: $t = 0.19$, $df = 66$, $p = 0.80$, $d = 0.14$).

Working memory

In the WAIS DS, no significant group differences emerged for any of the three test variables (DSF: $t = 1.75$, $df = 66$, $p = 0.086$, $d = 0.46$; DSB: $t = 1.69$, $df = 66$, $p = 0.104$, $d = 0.56$; DSF–DSB: $t = 0.09$, $df = 66$, $p = 0.925$, $d = 0.03$).

Comparison of subgroups and control group

The results of the comparison between the control group and the ADHD$^+$ group or the ADHD$^-$ group are not independent of the results between the two subgroups, but they nonetheless add information about the potential influence of comorbidity on task performance and are therefore reported here. The comparisons of effect sizes for instance display if one subgroup differs more strongly from the control group than the other subgroup regarding the dependent measures for set shifting and working memory. We found a slightly stronger effect for group differences between the ADHD$^+$ group and the control group than for differences between the ADHD$^-$ group and the control group on the CKV perseveration score ($d = 1.09$ vs. $d = 0.99$), the CKV concept perseverations ($d = 0.92$ vs. $d = 0.83$), and the WAIS DSF–DSB ($d = 0.72$ vs. $d = 0.66$). Based on the TMT shifting score, we found a larger effect size for the differences between the ADHD$^-$ group and the control group ($d = 0.82$) than for the difference between the ADHD$^+$ group and the control group ($d = 0.34$).

Significant group differences between the ADHD$^-$ group and the control group were found for the CKV perseveration errors ($t = -2.07$, $df = 49$, $p = 0.052$, $d = 0.96$), the perseverations score ($t = -2.29$, $df = 49$, $p = 0.03$, $d = 0.99$) and the WAIS DSB ($t = 4.207$, $df = 49$, $p = 0.000$, $d = 1.61$). On all other variables group, differences did not reach statistical significance (TMT A: $t = 0.90$, $df = 49$, $p = 0.374$, $d = 0.38$; TMT B: $t = -1.75$, $df = 49$, $p = 0.328$, $d = 0.77$; TMT shifting score: $t = -1.96$, $df = 49$, $p = 0.083$, $d = 0.82$; DSF: $t = 1.67$, $df = 49$, $p = 0.101$, $d = 0.69$; DSF–DSB: $t = -1.717$, $df = 49$, $p = 0.090$, $d = 0.66$). Between the ADHD$^+$ group and the control group t tests revealed significant differences on the TMT B ($t = -2.487$, $df = 48$, $p = 0.016$, $d = 0.98$), the CKV total errors ($t = -2.26$, $df = 48$, $p = 0.035$, $d = 1.03$), and the perseveration score ($t = 0.18$, $df = 48$, $p = 0.007$, $d = 0.88$). No significant differences were found for the remaining measures (TMT A: $t = 0.26$, $df = 48$, $p = 0.156$, $d = 0.62$; TMT shifting score: $t = -0.79$, $df = 48$, $p = 0.439$, $d = 0.34$; CKV perseveration errors: $t = -1.89$, $df = 48$, $p = 0.075$, $d = 1.03$; CKV concept perseveration: $t = -2.00$, $df = 48$, $p = 0.060$, $d = 0.92$; DSF: $t = -0.30$, $df = 48$, $p = 0.766$, $d = 0.12$; DSB: $t = 1.45$, $df = 48$, $p = 0.155$, $d = 0.60$; DSF–DSB: $t = 0.45$, $df = 48$, $p = 0.088$, $d = 0.72$).

Discussion

The primary aim of this study was to examine if adults with the combined type of ADHD display deficits in set shifting and working memory when compared to healthy control participants. Furthermore, patients with ADHD were separated into patients with and without comorbidity for a subgroup comparison, in order to rule out the possibility of differences between adults with and without ADHD being due to the comorbidity occurrence in the ADHD group.

We found that compared to the control group, the ADHD$_{total}$ group performed significantly poorer in both tasks for set shifting (i.e., TMT, CKV) applied in this study. The subjects with ADHD showed a higher TMT shifting score than healthy controls, which indicates ADHD-related difficulties in concept shifting and advanced planning. However, the high variability in performance among the patients, which is indicated by a high variance (i.e., standard deviation) in the patient group and an only moderate effect size, ($d = 0.47$) suggests that there is no general association between impairments in these domains and adult ADHD. Our results on the TMT are consistent with the previous studies that investigated set shifting by using a shifting score of the TMT or the CST, which is a modified form of the TMT (Marchetta et al. 2008; Stavro et al. 2007). When interpreting the poorer performance of the patient group on the TMT as deficits in set shifting, it is important to note that the TMT B is considered to be a measure of working memory by some authors also (i.e., Boonstra et al. 2005). This might be reasonable as the TMT B requires participants to hold in mind the last number or letter while searching for the subsequent number or letter. However, correlation analyses conducted in this study revealed very low correlations between the measure of working memory and the TMT B ($r = 0.05$) or the TMT shifting score respectively ($r = -0.03$). Our results therefore suggest that the results on the TMT are relatively independent of working memory function. This is in line with a study by Marchetta et al. (2008) that found only low correlations between a variant of the TMT and working memory tasks.

The higher perseveration score of ADHD patients in the CKV indicates their difficulties in modifying their strategy flexibly in response to negative feedback. This tendency to perseverate on a wrong strategy is confirmed by the significantly higher amount of concept perseverations in the $\text{ADHD}_{\text{total}}$ group. Concept perseverations indicate that a participant perseverates on a strategy even after receiving negative feedback three times. For the measures of the CKV, we found slightly higher effect sizes than for the TMT. This may be attributable to the fact that the CKV is a more complex test than the TMT, because it requires further high order cognitive abilities besides set shifting, as for instance sustained attention. It may be particularly difficult for patients with ADHD to switch flexibly between mental sets in situations with multiple cognitive demands (Clark et al. 2000). This difference between the CKV and the TMT might also explain why the analyses of the relationship between tasks revealed only low correlations between variables of the CKV and TMT. Our results on the CKV are in line with Seidman et al. (1997), who found that adolescents and young adults with ADHD make significantly more perseverative errors on the WCST compared to control participants. However, other researchers have failed to yield such differences between adults with and without ADHD on the WCST (Rapport et al. 2001). These highly inconsistent results may partly be explained by the different versions of the WCST that have been used in the studies. We chose a computerized version, as it is less sensitive for errors due to the automatization of execution and evaluation of the test. Overall, compared to the high number of studies that used the WCST to assess set shifting in children with ADHD, a little is known about the performance of adults with ADHD in this test. Thus, a great deal of research is necessary to validate our findings.

In everyday clinical practice, patients with ADHD are reportedly unable to organize and complete activities. These problems may partly be due to deficits in set shifting which may reduce the ability to organize complex activities, to modify plans when they turn out to be inefficient, and to make decisions based on multiple information. Thus, deficits in set shifting lead to problems in the organization of daily life. This applies to adults more than to children, as in childhood daily activities are more guided by parents and teachers. Thus, demands for flexibility and management increase with age. Adults may therefore benefit, especially from training programs where they learn how to identify inefficient organization strategies by using feedback from their environment, and learn how to modify these strategies.

With regard to the working memory task, this study revealed that in comparison with the control group, the $\text{ADHD}_{\text{total}}$ group has working memory deficits. The difference between both groups was of medium effect size. This finding is consistent with the previous studies that used the WAIS digit span to assess the working memory of adults with ADHD (Gropper and Tannock 2009; Walker et al. 2000). However, to our knowledge, our study is the only one that uses the WAIS digit span computing the difference of results on the DSF and DSB to isolate working memory abilities. Therefore, further studies are necessary to confirm this finding. The results regarding patients' working memory have important clinical implications: low working memory capacities are considered to be associated to the DSM-IV criteria for ADHD "does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace" and "is forgetful in daily activities" (Hervey et al. 2004). Hence, deficits in working memory contribute to difficulties in organizing everyday life. Working memory training programs may help adults with ADHD to hold information until a plan is realized, especially in the challenging situations with multiple distracting stimuli. However, the only medium effect size we found on the WAIS DS indicates that a deficit in working memory is unlikely to be a general neuropsychological deficit in adult ADHD.

The missing of large effect sizes in our study (especially on the WAIS DS and the TMT) might be explainable by the dual pathway model of behavior and cognition introduced by Sonuga-Barke (2002). According to this model

ADHD may not only pertain to a dysregulation of thought and action pathway (DTAP), but also to a motivational style pathway (MSP). Both patients with ADHD DTAP and ADHD MSP meet criteria for the ADHD combined subtype even though they are characterized by distinct symptoms, development, etiology, and cognitive profiles as described below. The first pathway (ADHD DTAP) is manifested in a primary inhibitory dysfunction that is mediated by secondary cognitive and behavioral dysfunctions, which in turn lead to faulty task-engagement (e.g., deficits of set shifting and working memory) and to symptomatic behavior (e.g., inattentiveness, hyperactivity). The second pathway (ADHD MSP) is characterized by a dysregulation of reward mechanisms leading to a higher preference for immediate rewards in children with ADHD. To examine this model, we recommend the inclusion of tasks for inhibition control and delay aversion in the future studies.

With respect to our approach to compute isolated scores for set shifting and working memory, our results on the TMT demonstrate the importance of this method: after computing the TMT shifting score as a measure for set shifting the effect size and the p value decreased (from $d = 0.61$ on the TMT Part B to $d = 0.48$ on the TMT shifting score and from $p = 0.012$ on the TMT Part B to $p = 0.05$ on the TMT shifting score). These results indicate that the poorer performance of the ADHD patients compared to control participants in the TMT B can partly be explained by a poorer performance on the TMT A (which is not a measure for set shifting). Thus, by only using the results on the TMT B score to assess set shifting performance, without controlling for the results on the TMT A, the difference between patients and controls would have been overestimated. This also holds true for the WAIS DS, on which the effect size decreased from $d = 0.72$ on the DSB to $d = 0.51$ on the DSF–DSB and the p value from $p = 0.003$ on the DSB to $p = 0.039$ on the DSF–DSB after computing the difference between the scores in the DSF and the DSB. In this regard, it is important to note that the present study assesses working memory defined as the simultaneous storage and manipulation of information. By some authors, the simple maintenance of information over a limited period of time, as measured by the DSF, is also considered as a function of working memory (i.e., Alloway et al. 2004; Gathercole and Pickering 2000). Following this view, computing the differences of the DSF and DSB leads to a loss of information concerning working memory abilities. Nonetheless, we still prefer the use of the difference between both subtests as the dependent measure for working memory, because it enables the control of functions as concentration and attention what we considered to be particularly important when examining ADHD patients.

Regarding the subgroup comparison, the ADHD^{+} group was found to perform poorer on the TMT Part A than the ADHD^{-} group. Thus, the ADHD patients with comorbidities showed impairments in visual scanning, psychomotor speed, and information processing speed, as measured by the TMT Part A. However, on the TMT shifting score, the measure for set shifting, no differences between the two ADHD subgroups could be found. With regard to the other variables for set shifting and the measure for working memory, no significant differences between ADHD patients with and without comorbidity could be found either. However, there is a trend toward a poorer performance in the ADHD^{+} group on the CKV perseverations score and the WAIS DSF–DSB indicating a slightly greater impairment when compared to the ADHD^{-} group in working memory and set shifting as measured with the CKV. This is confirmed by the higher effect size we found on these measures for the differences between the ADHD^{+} group and the control group compared to the effect size of the differences between the ADHD^{-} group and the control group. Thus, the poorer performance of the ADHD$_{total}$ group compared to the control group might partly be attributable to the presence of comorbidities in the patient group. However, given that differences between subgroups are very small and do not reach a statistical significance, our results suggest that the differences between patients and controls can mainly be explained by the presence of ADHD. Additionally, a comorbidity-related decline in set shifting as assessed with the TMT shifting score is unlikely, as mean scores indicated a better performance for the ADHD patients with comorbidities.

Thus, our results are partly in line with the previous studies that addressed the effect of comorbidities on EF in adults with ADHD. Marchetta et al. found ADHD-related deficits in concept shifting and verbal working memory that were independent of comorbidities. In a study by Murphy et al. (2001), young adults with ADHD also showed various EF deficits, which were not influenced by comorbidity. On the other hand, our study might also allow the support of a meta-analysis by Hervey et al. (2004) that found that adult ADHD patients with comorbid disorders show greater neuropsychological deficits than ADHD patients without comorbidity.

Limitations

With regard to the results on the subgroup comparison between patients with and without comorbidity, it is important to note that the ADHD^{+} group was highly heterogeneous regarding the range of comorbidities (see Table 2); therefore, the influence of single comorbid disorders was reduced. Additionally, the sample sizes of the subgroups ADHD^{+} and ADHD^{-} might have been too small and group differences that showed a trend of a poorer performance in the $ADHD^+$ group (i.e., perseveration score, DSF–DSB) might reach significance with larger sample sizes. Therefore, our results allow only a limited interpretation of the impact of comorbidity. Further research is necessary to investigate the potential influence of additional psychopathology on the EF performance in adult ADHD. However, ADHD is a clinically heterogeneous disorder (Biederman 2005) and this heterogeneity also relates to the high rate of various comorbid disorders in patients with ADHD (Sobanski 2006). Therefore, it is extremely difficult to completely control for comorbidities in a representative sample of adults with ADHD.

An additional limitation of our study relates to the working memory test. The WAIS DS is a verbal test and therefore assesses only the verbal working memory. No conclusions can be drawn about the performance of the nonverbal working memory. There is evidence that differences between children with and without ADHD are even larger for nonverbal working memory than for verbal working memory (Martinussen et al. 2005). Hence, the future research on working memory in adults with ADHD might want to include a wider range of tests to investigate all components of working memory.

A final limitation of our study concerns its generalizability, which is limited by the low number of female participants. The $ADHD_{total}$ group included 2 females and 35 males. This rate does not reflect the real ratio of females to males in adult ADHD, which is reported to be between 1:2 and 1:4 (Cuffe et al. 2005). The results of this study may therefore be more applicable to men with ADHD than to women with ADHD. However, as ADHD is a disorder that occurs more often in males compared to females; we nevertheless consider the implications of our study to be relevant.

Conclusion

The present study revealed deficits in set shifting and working memory in adults with ADHD. These deficits are not only an effect of comorbidity, although patients with comorbid disorders showed a slightly greater impairment in both domains compared to ADHD patients, but also without comorbidity. Our study supports the assumption that EF deficits are an important component in the neuropsychology of ADHD, but they are neither necessary nor sufficient to cause symptoms of ADHD (Willcutt et al. 2005).

Conflict of interest The authors declare that they have no conflict of interest.

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