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Regular Article

Multicomponent attention deficits in attention deficit hyperactivity disorder

BİRİM GÜNAY KILIÇ, MD,[1] ŞAHNUR ŞENER, MD,[2] AYLİN İLDEN KOÇKAR, PhD[2] AND SİREL KARAKAŞ, PhD[3]

[1]*Department of Child and Adolescent Psychiatry, Ankara University School of Medicine,* [2]*Gazi University Medical Faculty, Department of Child and Adolescent Psychiatry, and* [3]*Department of Experimental Psychology, Hacettepe University, Ankara, Turkey*

Abstract The aim of this study was to examine the specific aspects of attention, such as selective attention, sustained attention, and short-term memory in children with attention deficit hyperactivity disorder, combined subtype (ADHD-C). A total of 40 children with a diagnosis of ADHD from the 4th edition of the Diagnostic and Statistical Manual, aged 6–11 years old were compared with 40 controls matched for age and gender on a battery of tests. Short-term memory span and attention was measured by Visual Aural Digit Span Test–Revised. Stroop test and the Turkish version of Cancellation Test were used to assess selective and sustained attention, respectively. In order to check for factor structure in two groups on the test scores, principal component analysis was conducted for both groups separately. Relative to the comparison children, children with ADHD showed significant deficits on tests that are related to different aspects of attention. The results are consistent with the theories explaining the biological basis of ADHD by scattered attention networks in the brain, which have reciprocal dynamic interactions. Further comparative studies are needed to elucidate whether the cognitive processes that are known to be assessed by these tests are specific to ADHD.

Key words attention, attention deficit hyperactivity disorder, neuropsychology.

INTRODUCTION

Different hypotheses have been put forward to explain behavioral disturbances related to cognitive deficits in attention deficit hyperactivity disorder (ADHD). Neuropsychological studies have focused on vigilance and sustained attention, motoric inhibition, executive functions, and memory.[1,2] Delay aversion[3] and state regulation impairments[4] are two alternatives to consider as underlying at least some ADHD cases. Based on clinical and neuropsychological data it has been stated that both the orbitofrontal cortex and dorsolateral prefrontal cortex are functionally disturbed in ADHD.[5]

Two models explaining attentional processes through parallel information processing have been proposed. In both models the right parietal and cingulate cortex have an important role in spatial attentional processes.[6–8] The model proposed by Posner and Petersen[7] defines three interconnected nerve networks (executive control network, alerting network, orienting network).[9] Swanson *et al*. evaluates ADHD as a disorder related to these networks.[10] It has been emphasized that the controversy regarding the results of neuropsychological studies is semantic rather than substantive. The semantic issue here is believed to be that the term 'attention' has to be related to more than one anatomical network among several brain regions. A recent neuroimaging study has demonstrated altered brain mechanism in ADHD associated with all three attentional networks.[11]

The objective of the present study was to examine children in ADHD with respect to specific aspects of attention, such as selective attention, sustained attention, and short-term memory. Although a specific model of attention has not been adopted here, a battery of tests that is in relation with different aspects of attention was used. Therefore, it is hypothesized that attentional disturbance in ADHD is not limited to one

Correspondence address: Birim Günay Kılıç, MD, Sevil sokak No: 10/2 Cebeci, Ankara, Turkey. Email: birimkilic@yahoo.com

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aspect of attention, but different types of attention deficits need to be considered.

MATERIAL AND METHOD

Subjects

The participants were 40 children (8 girls, 32 boys), 6 to 11 years of age (mean, 8.3; standard deviation [SD], 1.4), who fulfilled 4th edition of the Diagnostic and Statistical Manual diagnostic criteria[12] for ADHD-combined subtype (ADHD-C) as determined by the first two clinical investigators. Children were recruited from the Department of Child and Adolescent Psychiatry of the Gazi University in Ankara, Turkey. Conners Teacher Rating Scale (CTRS-28) and Conners Parent Rating Scale (CPRS-48) were used for collecting multiple sources of information on the behavioral symptoms of attention deficit and disruptive behaviors disorders.[13] CTRS-28 and CPRS-48 confirmed the clinical diagnosis of ADHD-C. All children underwent a medical history, general physical and neurological examination. Subjects with a Full Intelligence Quotient >90 on the Wechsler Intelligence Scale for Children[14] were included. There was no repetition in their education and they did not attend special education classes. The exclusion criteria of the study were having a history of head injury or neurological deficit, a developmental delay, existence of conduct disorder, oppositional defiant disorder, mood disorder, anxiety disorder, and learning disorder.

The normal control (NC) subjects consisted of 40 children (6 girls, 34 boys), 6–11 years of age (mean, 8.3; SD, 1.3) who were matched with the study group. These children were recruited from the public school system which served populations characterized by socioeconomic levels similar to those of families of the experimental subjects. A child psychiatrist interviewed teachers who considered control subjects to achieve within the normal academic range. CTRS and CPRS were used in controls. The control children had no history of current medical, behavioral or attentional problems. The entire sample had never been exposed to psychotropic medications before the tests. Furthermore, children having color blindness and uncorrected sensory impairments were excluded from the study. The institutional ethical committee approved the study protocol. Written informed consent was obtained from parents of all children for participating in the research. The two groups of children, ADHD-C and NC, were matched by age and gender. Results indicated that groups did not differ on these variables ($t = -0.103$, $P = 0.92$; $\chi^2 = 0.346$, $P = 0.556$, respectively).

Behavior rating scales

Conners Parent Rating Scale

The CPRS-48 is a parent report questionnaire that surveys disruptive behavior problems in children.[13] The CPRS-48 was adapted in the Turkish population.[15]

Conners Teacher Rating Scale

The CTRS-28 was developed by Goyette *et al.*[13] The instrument's reliability and validity in screening attention deficit and disruptive behavior disorders for the Turkish children was obtained.[16]

Neuropsychological tests

Visual-Aural Digit Span Test–Revised

Visual Aural Digit Span Test–Revised (VADS-R) was based on the Visual Aural Digit Span (VADS) Test.[17] VADS Test was originally designed as a diagnostic tool for assessing reading and learning disabilities in primary school children and is specifically used for measuring attention span.[18,19] The VADS-R was standardized for Turkish children between the ages of 6–11 years. Test–retest reliability coefficients conducted after a 2-month period are between 0.54 and 0.82.[20]

VADS-R measured digit span from a multimodality perspective. The subtests of VADS-R were given a standard order as follows: aural-oral (AO), visual-oral (VO), aural-written (AW) and visual-written (VW). Testing started with a two-digit item; the longest series included nine digits. The child was asked to respond in the appropriate modality 1 s after the presentation of the last digit of a given item. The instructions required the child to learn and recall the digits one by one and not to use mnemonic or organizational strategies. In the oral response mode, the child was asked to repeat the series aloud; in the written response mode, the child was asked to write the digits on A4 size paper. The scores in the VADS-R were based on the number of digits in the longest series that were correctly reproduced by the participant.

VADS-R produced 11 scores. The subtests produced four basic scores and each score varied between 0 and 9. Combinations of subtest scores produced six combination scores and these varied between 0 and 18. The total score varied between 0 and 36. The basic scores were AO, VO, AW, and VW. The combination scores were aural input (AI) score (AO + AW), visual input (VI) score (VO + VW), oral expression (OE) score (AO + VO), written expression (WE) score (AW + VW), intrasensory integration (INTRA) score (AO + VW), intersensory integration (INTER) score (VO + AW), and total (TOTAL) score (AO + VO + AW + VW).

Stroop test

The Stroop Test[21] is used in the literature to assess selective attention and response inhibition. The basic principle of the test is to create interference between word reading and color naming. This interference is observed as an increase in the reaction time and in the errors in incongruent tasks compared to congruent tasks.

The present study used the Stroop test TBAG (Turkish Scientific and Technical Research Council of Turkey) version.[22] Stroop Test TBAG version represents a combination of the original Stroop Test[21] and the Victoria Version.[23] The presentation of the test is in card form like the original form. TBAG version was developed within the context of the Neuropsychological Test Battery for Cognitive Potentials.[22] The Stroop TBAG Form was standardized for Turkish children with ages between 6 and 11 years. The reliability measures were conducted by the test–retest method after a 2-month period and reliability coefficients were found to be between 0.63 and 0.81.[24]

Stroop TBAG has five subtests that sequentially involve reading color words that are printed in black (STR/1), reading colored words that denote different colors (STR/2), naming color of colored circles (STR/3), naming color of colored neutral words (STR/4), and naming color of colored words where color and meaning are incongruent for some of the words (STR/5). The test renders scores on time to completion/duration (D), number of errors (E) and number of corrected responses (C) for each part of the test (1–5).

Verbal and non-verbal Cancellation Test

Verbal and non-verbal Cancellation Test (CT) was originally developed by Weintraub and Mesulam to measure a sensory component that is related to perceptual representations, a motor component that is related to visual search and scan, and a motivational component that is related to affect.[25] CT is used in the literature as a measure of visuo-spatial skill and vigilance/sustained attention.[26] The Turkish version was developed within the context of the Neuropsychological Test Battery for Cognitive Potentials.[22] CT was standardized for Turkish children between the ages of 6 and 11 years. The test–retest reliability coefficients of CT scores changed between 0.45 and 0.83.[27]

CT has four subtests: organized letters (OL), organized figures (OF), random letters (RL), random figures (RF). For each subtest, CT renders scores pertaining to correct responses (1), omission errors (2), commission errors (3), total number of incorrect responses (4), and time to completion/duration (5). The form in each subtest contains 60 target items. There are 15 target stimuli in each quadrant. Participants are required to circle the target stimuli.

Procedure

Children were tested individually in two different sessions by trained clinicians. One session included VADS-R and the second session included CT and Stroop TBAG. The order of the sessions and the order of the tests within each session were randomized.

Statistical analysis

To determine if differences existed between the two groups, a MANOVA was conducted using group as the independent variable, and the different sets of neuropsychological measures as dependent variables. In order to check for differences of the factor structure in ADHD-C and controls on VADS-R, Stroop Test and CT scores, principal component analysis (PCA) was conducted for both groups separately. 'Kaiser normalization' was used in order to see how many of the scores used in the PCA were significantly different than zero.[28] Factors greater than 1.00 were used in the results and the effect of these to the shared variance is discussed. Varimax rotation was conducted to the results of the PCA. Factor loadings less than 0.316 after the varimax rotation were not taken into consideration.[29] Data were analyzed with SPSS 13.0 for Windows (SPSS Inc., Chicago, IL, USA). *P*-values <0.05 were considered significant.

RESULTS

ADHD-C and NC groups differed on the basis of VADS-R, Stroop Test and CT scores (Wilks' $\lambda = 0.504$, $F[22, 57] = 2.546$, $P = 0.002$; Table 1). It was found that performances of the ADHD group in the visual-oral and visual-written subtests of VADS-R were lower compared to the controls. In contrast, those components that do not have visual input, namely, aural-oral, aural-written, and the combination score of these subtests aural input (AO + AW) were not found to be significantly different in the two subject groups. This indicated that ADHD subjects had more difficulty in expressing material presented in visual modality of both oral and written format compared to normal subjects.

Table 1. Neuropsychological measures, means and standard deviations for two groups (MANOVA)

Test	Subtest	ADHD-C (*N* = 40) Mean (SD)	Controls (*N* = 40) Mean (SD)	F	*P*
VADS-R	Aural-Oral (AO)	4.13 (1.07)	4.48 (0.85)	2.641	0.108
	Visual-Oral (VO)	3.63 (1.31)	4.60 (0.96)	12.924	**0.001**
	Aural-Written (AW)	3.98 (1.64)	4.45 (0.93)	2.534	0.115
	Visual-Written (VW)	3.78 (1.49)	4.80 (0.94)	13.503	**0.000**
	Aural Input (AO + AW)	8.10 (2.31)	8.93 (1.56)	3.488	0.066
	Visual Input (VO + VW)	7.40 (2.50)	9.35 (1.69)	16.724	**0.000**
	Oral Expression (AO + VO)	7.75 (2.06)	9.03 (1.56)	9.736	**0.003**
	Written Expression (AW + VW)	7.75 (2.66)	9.25 (1.74)	8.931	**0.004**
	INTRA (AO + VW)	7.90 (2.32)	9.28 (1.47)	10.046	**0.002**
	INTER (VO + AW)	7.60 (2.64)	9.00 (1.65)	8.097	**0.006**
STROOP	STR/1 Time (s)	20.38 (12.37)	17.88 (14.73)	0.676	0.414
	STR/2 Time (s)	21.58 (12.00)	17.48 (11.60)	2.413	0.124
	STR/3 Time (s)	25.88 (8.58)	20.90 (6.36)	8.861	**0.004**
	STR/4 Time (s)	38.70 (13.22)	32.50 (9.74)	5.702	**0.019**
	STR/5 Time (s)	55.20 (18.90)	43.88 (10.60)	10.922	**0.001**
CT	Correct responses	56.00 (4.57)	57.85 (2.85)	4.712	**0.033**
Organized letters (OL)	Omission errors	4.00 (4.57)	2.15 (2.85)	4.712	**0.033**
	Commission errors	0.10 (0.38)	0.03 (0.16)	1.335	0.252
	Duration (s)	246.38 (116.47)	201.63 (91.46)	3.652	0.060
CT	Correct responses	56.28 (5.15)	58.55 (1.50)	7.184	**0.009**
Organized figures (OF)	Omission errors	3.78 (5.14)	1.45 (1.50)	7.550	**0.007**
	Commission errors	1.35 (1.64)	0.93 (1.21)	1.741	0.191
	Duration (s)	211.38 (75.44)	193.03 (64.57)	1.366	0.246
CT	Correct responses	56.15 (4.72)	57.85 (2.52)	4.046	**0.048**
Random letters (RL)	Omission errors	3.85 (4.72)	2.15 (2.52)	4.046	**0.048**
	Commission errors	0.05 (0.22)	0.00 (0.00)	2.053	0.156
	Duration (s)	247.65 (90.07)	215.40 (77.05)	2.962	0.089
CT	Correct responses	56.10 (4.83)	57.38 (4.34)	1.542	0.218
Random figures (RF)	Omission errors	3.90 (4.83)	2.63 (4.34)	1.542	0.218
	Commission errors	0.93 (2.15)	0.18 (0.38)	4.704	**0.033**
	Duration (s)	191.90 (64.40)	155.53 (55.09)	7.869	**0.008**

Significant p values defined in bold letters.

ADHD-C, Attention Deficit Hyperactivity Disorder – Combined Type; CT, Cancellation Test; VADS-R, Visual-Aural Digit Span Test–Revised.

According to the Stroop Test results, lower performance of children with ADHD in all color naming subtests was observed. In contrast, in the reading-only subtests significant differences were nonexistent between the ADHD and control groups. This indicates a higher deficit in ADHD subjects in color-naming and Stroop interference effect in terms of the observed increase in the reaction time and in the errors in incongruent tasks compared to congruent tasks.

Cancellation Test results showed that children with ADHD showed lower reaction speeds and higher omission/commission errors in CT compared to controls in different subtests of CT. In three of the four subtests of CT, namely, Organized Letters, Random Letters and Organized Figures, finding correct responses and omission of targets were significantly different for ADHD and controls. In contrast, commission errors indicating impulsivity and completion time of CT subtests indicating reaction speeds were higher in ADHD subjects in CT Random Figures subtest.

VADS-R, Stroop, and CT scores were subjected to PCA for the NC group. Five factors were extracted with eigenvalues 7.52 through 1.42 and these factors were found to explain 81.79% of the variance.

VADS-R, Stroop, and CT scores were subjected to PCA for the ADHD-C group. Four factors were extracted with eigenvalues 7.87 through 3.35 and these factors were found to explain 68.87% of the variance.

VADS-R subtest scores that assess attention and short-term memory were gathered under the first factor for both the control and study groups.

For the Stroop test, all the reading and color-naming scores were gathered under factor two for the control group, whereas for the ADHD group only reading scores were under factor two. Stroop scores regarding color-naming and interference effect were gathered under a third factor for the ADHD group.

For CT, in terms of the correct responses, it was found that in the normal control group, scanning behavior was differentiated in terms of the pattern of the stimulus (organized/random) and gathered under different factors (factors 4 and 5). In contrast, in the ADHD group there was no differentiation with regard to the stimulus pattern or type.

DISCUSSION

The processes in the information processing paradigm are being investigated as the core deficit in ADHD and empiric findings aid in the development of different theories. The conceptual basis of these theories lie on overlapping models related to executive functions, working memory, attention and inhibition.[30]

In this study it was found that there are deficits in vigilance/sustained attention as well as other attention measures in children with ADHD. These results are consistent with the theories explaining the biological basis of ADHD by scattered attention networks in the brain, which have reciprocal dynamic interactions. These tests are connected with executive functioning such as response organization and working memory, functions which are related to attention.

An important finding in this study is the low performances of the ADHD group in the visual-oral and visual-written subtests of VADS-R. In these subtests, the subject is expected to memorize a set of visually presented number sequences and then give the responses in writing. In this formation that requires monitoring, there is an analogy between a digit span test and working memory. This result shows a parallel structure with previous results comparing memory capacity through digit span.[31–33] The lower performance of subjects with ADHD in attention and memory test is taken as a dysfunction related to working memory.[30,31] A recent meta-analysis has shown that there are deficits in many of the components of the working memories of ADHD children, regardless from learning disorder and IQ.[34]

VADS-R assesses short-term memory span, sequencing and motor integration. It is also a serial learning task that necessitates temporal ordering. Serial ordering and sequencing are frontal lobe functions.[35,36] Fuster[37] has pointed out that temporal ordering which is important in terms of learning and memory is a function of the dorsolateral prefrontal cortex. Studies have also shown the important role of fronto-striatal dopaminergic circuit in working memory.[38] Serial learning also comprises proactive interference. Orbitofrontal cortex is related to resistance to interference, therefore, closely related to serial learning.[39] The dysfunction of these circuits in ADHD has been shown through neuroimaging studies.[40,41]

The ADHD children were impaired in the visual modality of the VADS-R in this study, which is like Penney's separate-streams model of short-term verbal memory.[42] According to this model, verbal information presented in aural and visual modalities are processed in separate channels with different characteristics and capacities. Aural stimuli elapse into phonological formats much more automatically. In contrast, visual stimuli necessitate a transformation in order to elapse into phonological formats. Clinical studies show that the visual system gains its full function later developmentally and that it is more sensitive to brain damage.[43] Electrophysiological and neuroimaging studies also show that there are quantitative differences in activation patterns of the brain in visual and aural verbal working memory tasks without performance differences.[44,45] Therefore, it can be concluded that the lower performance of the visual short-term memory, which requires more attentional functions and neuronal capacity, of ADHD children is related to insufficient attentional functions. This result brings on inferences related to psycho-education. It might be reasonable to increase ADHD children's learning abilities through visual materials that are reduced in cognitive content by dividing materials into simple pieces and supporting these by speech-based instructions.

In a neuro-imaging study in which the Stroop effect was investigated in normal adults, all brain regions that showed activation were shown to have functional links with the anterior cingulate (AC).[46] Based on these results, the role of AC on attention networks and executive functions such as conflict resolution and impulse control has been pronounced. These neural networks, especially the frontal cortex, are brain regions believed to have an important role in the pathology in ADHD.[47] In this study, the lower performance of children with ADHD in all color naming subtests, which is less automatic than reading and requires more attention, is in favor of attentional-executive dysfunction.

In a recent meta-analysis in which children with ADHD were assessed in terms of interference with the standard Stroop Color-Word Task, it was found that there was a higher and more homogenous effect in word reading and color naming, whereas there was a lower effect in interference score.[48] It was also found that children with ADHD showed a lower performance in all the Stroop scores.[48]

Cancellation tests assess vigilance, visual search and speed of response. Ability to attend to visual stimuli based on their spatial locations requires the parietal cortex.[26] These tests, which assess selective and sustained attention in children, also have properties such as memorizing the target and learning, using strategies, giving planned responses and the continuance of the behavioral formation that include executive function properties.[49]

Clinical research to use cancellation tests under time pressure has shown both positive and negative results in terms of differentiating patient groups from controls.[49–51] There have been significant differences in terms of completion time, omission and commission errors between controls and ADHD children.[52] In this study, it was found that children with ADHD showed lower reaction speeds and higher omission/commission errors in CT. These results are important, because CT results suggested that there are sustained attention deficits related to parietal attention networks as well as dysfunctions in the frontal attention network structures which are shown by the first two tests.

PCA of test scores from these two groups yielded different results: The controls showed a coherent factor structure compared to that of the ADHD group. When evaluated in terms of the correct responses, it was found that in the normal control group, scanning behavior was differentiated in terms of the pattern of the stimulus (organized/random) and gathered under different factors (factors 4 and 5). In contrast, in the ADHD group there was no differentiation with regard to the stimulus pattern or type. This result also shows that there are focused and sustained attentional deficits in ADHD.

The current findings must also be interpreted in light of certain limitations. This study is cross-sectional and conducted with subjects of ADHD-C subtype. Therefore, results may not be true for all ADHD subtypes. In contrast, the strong part of this study is the usage of standardized tests with normative data that have previously been studied in a large population of Turkish children.

To sum up the current results, the battery of tests in this study did have a discriminating power; abnormal scores on the tests were suggestive of ADHD diagnosis. Further comparative studies with other psychiatric disorders are necessary to find out whether the cognitive processes that are known to be assessed by these tests are specific to ADHD.

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