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Original Article

Executive Function in Attention Deficit/Hyperactivity Disorder

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ABSTRACT

Aim: To assess executive functions in medication naïve children with attention deficit/hyperactivity (ADHD). **Method:** Group matched (age and gender) children with ADHD (N=30) and healthy children (N=30) in the age range of 6-14 years were compared on measures of executive functions (response inhibition, working memory, cognitive flexibility, fluency and planning). **Results:** ADHD children had significant deficits in response inhibition, working memory, cognitive flexibility and design fluency. **Conclusions:** The results suggest that deficits in executive functions may be a central feature of ADHD.

Keywords: ***Executive functions; Attention deficit/hyperactivity disorder; Response inhibition; Working memory***

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a common childhood onset behavioral disorder that affects up to 9% of school-age children.[1] The conceptualization of this disorder started with a notion of "minimal brain damage syndrome" to progress later as purely a functional disorder and now stresses back its association with neurological abnormalities. Prefrontal cortex, particularly orbitofrontal and dorsolateral cortices, and its connections to striatum and cerebellum are hypothesized to play a pivotal role in pathology of ADHD.[2] This shift in understanding is attributed partly to the recognition of higher-level cognitive deficits, involving predominantly executive functions.[3,4]

Executive functions are commonly described as mental control processes that are necessary to maintain an appropriate problem-solving set for the attainment of a future goal and programming and planning of motor and behavior skills.[5] They actually encompass different metacognitive domains including fluency, working memory, planning and foresight, cognitive flexibility and response inhibition. Researchers are not in agreement regarding the importance (e.g. whether executive dysfunctions are a core cognitive deficit) or nature (e.g. specific domains) of executive function deficits in ADHD; explanations for the heterogeneity of findings; and effect of stimulants and other available medications for ADHD on executive functions.[6] Relatively strong evidence has accrued for inhibitory deficit as the primary cognitive dysfunction; and for working memory deficits in ADHD.[3,4,6,7]

In the present study, we have tried to assess all major domains of executive functions in medication-naïve children, unlike most previous studies that have assessed only a limited number of executive functions (e.g. verbal and visual aspects of fluency and working memory, and planning have drawn limited research attention) in samples that have included children on medication.[8] Also, we couldn't find any input to this topic from India, where ADHD is an equally significant problem.[9]

METHODS

The study was conducted with 2 groups of age and sex matched children in the age range of 6-14 years; the 'experimental group' consisting of 30 children diagnosed with ADHD and a 'control group' consisting of 30 healthy children. The children were approached for participation in their 'first contact' with the Child Guidance Clinic of All India Institute of

Medical Sciences, Delhi while they were 'medication naïve' with respect to ADHD. Written informed consent was obtained from the parents before inclusion of children in the study.

The diagnoses of psychiatric disorders (including ADHD) were made by a qualified psychiatrist based on the DSM-IV-TR criteria. Information obtained on the Conner's Parent Rating Scale - Revised (CPRS-R) was also used in making the diagnosis.[10] CPRS-R collects information from parents for children and youth (3-17 years) on opposionality, inattention, hyperactivity-impulsivity, anxiety and shyness, perfectionism, social problems and psychosomatic complaints. All children had an Intelligence Quotient (IQ) of >80 based on Malin's Intelligence Scale for Indian Children;[11] an Indian adaptation of Weschler Intelligence Scale for Children. Children with mental disorders other than specific learning disorders (SLD), oppositional defiant disorder (ODD) and conduct disorder (CD) were excluded from the experimental group. Children with physical disorders, and visual or hearing impairment were excluded from both groups based on clinical examination and appropriate investigations.

Executive Function Tests: The executive functions were assessed with 5 tests taken from the NIMHANS Neuropsychological Battery for Children.[12] These were administered in 3 sessions (maximum duration: 35 minutes) conducted on 3 different days.

Fluency

Phonemic Fluency Test[13]*:* The participant is asked to produce orally as many words (no proper nouns) as possible beginning with given letters - F, A and S; with 1 minute for each letter. The sum of all admissible words for the three letters was the score for the test.

Design Fluency Test[14]*:* The participant is asked to draw meaningless designs, using only 4 lines in 4 minutes for fixed response section and any number of lines in 5 minutes for free response section.

Working memory

Verbal N-Back Test[15]*:* The participant should respond by tapping for phonetically similar sounds presented consecutively in 1-back test and with a gap of 1 dissimilar phoneme in 2-back test. Each phoneme is presented verbally at the rate of 1 phoneme per second.

Visual N-Back Test[15]*:* The participant is presented two sets of 36 cards. There is 1 dot placed on spatially different locations in every card in an imaginary circle. The cards are successively placed on the table in the same manner at the rate of 1 card every 2 seconds. The matching sequence is similar to Verbal N-Back Test.

Planning

Porteus Maze Test[16]*:* The participant is instructed to trace the maze from the starting point to its free end without crossing any line, going to blind end or lifting the pencil before reaching the free end. Scores are computed based on comparison of performance test-age with the chronological age.

Cognitive flexibility

Wisconsin Card Sorting Test[17]*:* The test consists of 4 stimulus cards varying in number, colour and geometric form. The participant is given two packs of 64 response cards, which have designs similar to those on stimulus cards in one or more categories. S/he is asked to match each of them to one of the 4 stimulus cards. S/he has to follow a specific sequence of categories about which feedback is given in terms of right or wrong matching. The test is continued until the subject has successfully completed 6 sorting categories (form, colour and number, each repeated twice) or until both packs of cards have been used. The raw scores are converted into 'T-scores' according to provided norms.

Response Inhibition

Stroop Test[18]*:* This test has 2 sections with 1 sheet for each section, in which the name of the colours are written either in congruent or non-congruent ink. In first section, the participant is asked to read the written names of colours irrespective of the ink-colour used. In the second section, s/he has to name the ink-colour with which name of the colour is written without focusing on congruency. The scoring for each section is based on the number of errors and the time taken to complete the task.

Group comparisons were done based on $\chi2$ test for categorical variables and unpaired t-test (normal distribution) or Wilcoxon rank sum test (skewed distribution) for quantitative variables. A logistic regression analysis was conducted to examine the significance of variables in a multivariate space.

RESULTS

The mean age of participants was 9.57 years. Four fifths of the participants were boys. The two groups did not differ significantly in terms of IQ scores and socio-demographic variables. The distribution of subtypes of ADHD in the experimental group was: combined type - 54%, hyperactive-impulsive type - 13%, and inattentive type 33%. Out of the 30 children in the ADHD group, 4 had SLD, 4 ODD and 2 CD. None of them had more than one co-morbid disorder.

The control group performed significantly better than the ADHD group on the free response section of design fluency test (p=0.021); some of the quantitative parameters of WCST - total number of errors (p=0.001), perseverative errors (p=0.001), percent perseverative errors (p=0.006) and percent conceptual level responses (p=0.034), perseverative responses (p=0.012), and percent perseverative responses (p=0.009); and all parameters of the Stroop test – mistakes-1 (p=0.028), time-1 (0.036), mistakes-2 (0.014), and time-2 (0.025) (Table 1).

Table1: Group comparison on Quantitative Variables of Executive Functions Tests

	ADHD Mean (SD)	Control Mean (SD)	Probability based on t test/ Wilcoxon rank sum test[a]
Phonemic fluency			
Words	11.03 (4.66)	14.1 (7.1)	0.111
Design fluency			
Fixed response	10.1 (3.16)	11.2 (3.83)	0.312
Free response	17.2 (4.83)	21.6 (5.29)	0.021*
Porteus Maze Test			
Age score	121.3 (18.98)	127.2 (18.34)	0.106
Wisconsin Card Sorting Test			
Total number of errors	47.9 (7.9)	58.7 (9.2)	0.001*
Perseverative errors	47.6 (7.1)	58.5 (8.6)	0.001*
Percent perseverative errors	48.27 (6.2)	57 (7.3)	0.006*
Percent conceptual level responses	50.4 (7.5)	56.17 (9.6)	0.034*
Non-perseverative errors	53.9 (7.9)	57.5 (8.2)	0.071
Percent non-perseverative errors	48.6 (5.2)	52.4 (6.3)	0.068
Perseverative responses	48.7 (6.6)	58.6 (8.0)	0.012*
Percent perseverative responses	49.5 (5.8)	58.2 (7.0)	0.009*
Stroop Test			
Mistakes-1[a]	1.33 (1.55)	0.5 (1.0)	0.028*
Time-1 (seconds)	76.73 (29.5)	62.27 (22.3)	0.036*
Mistakes-2[a]	6.0 (3.33)	4 (2.18)	0.014*
Time-2 (seconds)	171.6 (42.43)	145.8 (44.24)	0.025*

[a]Wilcoxon rank sum test, *p<0.05

The participants were categorized based on designated cut-off scores of the N-back task. The control group performed significantly better than the ADHD group on verbal 2-back (p=0.03) and visual 1-back (p=0.003) tests (Table 2). The participants were categorized into 2 subgroups around on the 16^{th} percentile of the following parameters of WSCT: number of categories completed, number of trials taken to complete first category, failure to maintain set and learning to learn. The control group performed significantly better on the trials to complete first category (p=0.000) and failure to maintain set (p=0.024).

Table 2: Group comparison on Categorical Variables of Executive Functions Tests

	ADHD (N=30)	Control (N=30)	Probability based on $\chi 2$ test
N back task			
Verbal 1 back	22 08	25 05	0.147
Verbal 2 back	16 14	23 07	0.03*
Visual 1 back	14 16	25 05	0.003*
Visual 2 back	27 03	28 02	0.340
Wisconsin Card Sorting Test			
Number of categories completed	23 07	29 01	0.072
Number of trials taken to complete first category	17 13	30 00	0.000*
Failure to maintain set	20 10	28 02	0.024*
Learning to learn	12 18	19 11	0.257

*p<0.05

The executive functions that differentiated the ADHD and control groups were subjected to a logistic regression (Table 3). Eight variables related to executive dysfunction remained significantly discriminatory for ADHD and control groups. The dysfunction in working memory (Verbal 2 back and Visual 1 back cut-offs) was most predictive of ADHD group membership. The other variables with significant odds ratio were mistakes-2 in Stroop test, free responses in design fluency test and some quantitative variables of WCST.

Table 3: Results of logistic regression

Variable	Odds Ratio	95% Confidence Interval for Odds Ratio	Probability (p<0.05)
Design fluency (free responses)	1.715	1.12-2.164	0.000
Verbal 2 Back (cut off)	5.415	1.072-7.351	0.041
Visual 1 Back (cut off)	9.592	1.790-15.387	0.008
Stroop test (mistakes-2)	2.66	1.86-3.931	0.027
WCST (total number of errors)	1.39	1.014-1.95	0.002
WCST (perseverative errors)	1.132	1.044-1.227	0.003
WCST (percent perseverative responses)	2.171	1.56-2.98	0.003
WCST (percent perseverative errors)	1.45	1.17-1.74	0.002

DISCUSSION

The present study supports the presence of executive dysfunction in ADHD; and suggests the possibility that impairment of response inhibition and working memory are the core deficits in ADHD. Importantly, the study is not burdened by the usual confounders of studies on executive function, e.g. low IQ, use of cognition-altering medication, or high comorbidity. The comprehensiveness of the executive functions selected for study, e.g. the inclusion of both a visual and a verbal n-back task and both a verbal and a design fluency task; can be seen as strength of the study. However, the study should be seen as a preliminary attempt to examine executive functions in ADHD in India as the small sample size compromises its generalizability. The presence of few girls and few children in specific age ranges precluded the examination of the impact of gender or development on executive functions. The results of WCST should be taken as tentative as the test has not been standardized for the Indian population. Finally, the performance of the ADHD group on language based tests in the battery would have been affected by that the presence of some children with SLD in the group (they would have performed poorly on language based tasks independently of their executive function skill deficts).

Response inhibition

Our Stroop test results support suggestions that poor response inhibition is an important executive dysfunction in ADHD.[4,7,8] Since, ADHD group was more likely to commit errors rather than respond slowly on the Stroop test, the theory of ‘Delay Aversion’ proposed by Sonuga-Barke, which considers motivational factors as more important than executive functions in ADHD, is not supported.[19] The ADHD group had flatter performance in the second section of the test indicating that the children with ADHD have greater difficulty in inhibiting responses when faced with greater interference from the stimulus.

Working memory

We found interference in verbal (2-back) and visual (1-back) areas of working memory in children with ADHD, unlike a meta-analysis that showed greater effect sizes for spatial working memory.[20] Authors have suggested that working memory dysfunction may be associated with co-morbidity rather than ADHD per se;[21,22] hence further research on larger samples with adequate representation of comorbid disorders is warranted.

Cognitive flexibility

The ADHD group performed poorly compared to the control group on some parameters of WCST, including total errors and perseverative errors. Literature support for lack of strategic flexibility in children with ADHD is accruing.[3,23] However, Willcutt et al[24] found only mild/moderate dysfunction in set shifting in ADHD in their meta-analysis.

Fluency

The ADHD group had significant deficit only on the free response condition of design fluency. Previous literature in this area has been contradictory, with some studies supporting deficits in fluency;[20] and others reporting negative results.[4,21] Differences in tests used (e.g. design fluency tests have not been used previously) and presence of confounders (e.g. medication, comorbidity) could explain the differences in results of various studies.

Planning

This study doesn’t favour impairment of planning in ADHD. Negative results have been reported by some studies;[25] but, other studies and a meta-analysis have suggested significant deficit in ‘planning and problem solving’ in children with ADHD.[24,26] Methodological issues, e.g. use of different tests (e.g. the ‘Trail tower test’) and sample size considerations (inadequate power to pick up the mild impairment in planning in ADHD e.g. in comparison with autism[27]) may explain these differences between studies.

Biederman and coworkers observed that children with ADHD with impaired scores on 2 or more executive functions measures had twice the likelihood of repeated grades and placement in special educational classes than those without such impairment.[28] This implicates the need for additional focus on management of ADHD children with executive functions deficit. However, the path towards the exploration of the role of executive functions in clinical manifestations and outcome of ADHD is long. This study is a step in that direction.

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