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**REVIEW PAPER**

# Specific Cognitive Deficits in ADHD: A Diagnostic Concern in Differential Diagnosis

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Running head: Diagnosis of ADHD

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## Abstract

We present a critical account of existing tools used to diagnose children with Attention Deficit Hyperactivity Disorder and to make a case for the assessment of cognitive impairments as a part of diagnostic system. Surveys have shown that clinicians rely almost entirely upon subjective reports or their own clinical judgment when arriving at diagnostic decisions relating to this prevalent disorder. While information from parents and teachers should always be carefully considered, they are often influenced by a host of emotional and perceptual factors. It increases the possibility for misdiagnosis of a condition like ADHD. Recent experimental literature on ADHD has identified unique underlying cognitive dysfunction, specific to ADHD. Therefore, we propose that there is a need to incorporate information on cognitive mechanisms underlying ADHD and inculcate such information in the diagnostic system, which will provide a more sensitive as well as specific tool in differential diagnosis of ADHD.



Key Words: Attention Deficit Hyperactivity Disorder, Oppositional Defiant Disorder, Differential Diagnosis, Diagnostic System, Specific Cognitive Functions.

## Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common developmental cognitive disorders of childhood. Prevalence rate of ADHD is 3-7% of children in the United States, and often continuing into adulthood (Barkley, 1998). ADHD is usually characterized by a pattern of increased impulsivity, high levels of motor activity, and attentional problems that impair function in home, school, and social settings (American Psychiatric Association, APA, 1994). Children with ADHD usually have functional impairment across multiple settings including home, school, and peer relationships. ADHD also has been shown to adverse effect on academic performance, vocational success and social-emotional development. The prevalence rate of ADHD has drastically increased. The increase is probably due to changes in diagnostic criteria. It is important to diagnose ADHD correctly otherwise they will not get proper treatment. Diagnosis of a disorder like ADHD is a complex issue for a clinician because of the high prevalence of co-morbid conditions. Misdiagnosis is likely to happen which may resulted in serious consequences, including school failure, depression, conduct disorder, failed relationships, and substance abuse (APA, 1994). Therefore, proper diagnosis of ADHD children is very important. However, clinicians often cannot diagnose children with ADHD accurately consequently, these patients treated inappropriately in the primary care setting.

There is no laboratory test or set of physiological features that has been identified as an unequivocal marker for ADHD. That is, there is no "gold standard" for diagnosing ADHD. The disorder is behaviorally based; thus, behavioral observations are required to identify and correctly diagnose the disorder. It has been argued that ADHD is not a distinct diagnostic entity, but that it is a "symptom complex" characterized by multiple possible etiologies and a constellation of pathological behaviors (Weinberg & Brumback, 1992; Weinberg, 1993). The observed behaviors are interpreted subjectively by parents and teachers who describe these observations to clinicians. Clinicians often observe the child during clinical interviews and psychometric testing. Typically, parent, teacher and clinical observations are incorporated into a diagnostic decision. However, this subjective interpretation can lead to inter-observer differences, and can make ADHD diagnosis difficult. For example, the prevalence of behaviors related to hyperactivity as rated by a teacher can be higher than that rated by a clinician (Lambert et al., 1973). In contrast, the prevalence of behaviors related to hyperactivity can be lower if these behaviors must be judged to be present by more than one source (e.g., parent and teacher) (Sandberg et al., 1980).

Because there is no gold standard for diagnosing ADHD, it is important to make a distinction between how ADHD is defined and how it is diagnosed. The disorder is currently defined by criteria contained in the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV). The DSM-IV defines ADHD according to two behavioral domains: inattention and hyperactivity-impulsivity. Each domain contains nine possible symptoms; a child must have at least six of the nine symptoms to qualify for a diagnosis of ADHD. If the child has at least six symptoms on the inattention domain, s/he qualifies for the "ADHD-Predominantly Inattentive Type" diagnosis. If the child has at least six symptoms on the hyperactivity-impulsivity domain, s/he qualifies for the "ADHD-Predominantly Hyperactive-Impulsive Type" diagnosis. If the child has at least six symptoms on both inattention and hyperactivity-impulsivity domains, s/he qualifies for the "ADHD-Combined Type" diagnosis (DSM-IV).

Additional DSM-IV criteria specify that some inattentive or hyperactive-impulsive symptoms must have been present before the age of seven years, although the diagnosis can be made at older ages. In addition, the symptoms must be present in at least two settings (e.g., home and school) and must cause impairment. That is, there must be evidence of interference with developmentally appropriate social, academic, or occupational functioning. The symptoms should not occur exclusively during the course of a pervasive developmental disorder (e.g., autism), schizophrenia, or any other psychotic disorder. Furthermore, the symptoms should not be better accounted for by another mental disorder (e.g., mood, anxiety, dissociative or personality disorders) (DSM-IV).

While ADHD is defined by the DSM-IV criteria, the symptom complex is diagnosed by a clinician. In the absence of a gold standard, the "reference standard" is the clinician's judgment. Ideally, this decision would be based on information gathered from a number of sources (e.g., parent, teacher, observations of the child), and would be reached by consensus. That is, a number of qualified clinicians would confer in making the appropriate diagnosis. Nevertheless, the clinician's decision is ultimately a subjective one, and this introduces a level of variability that is difficult to control particulary while evaluating a tool used for the diagnosis of ADHD. Moreover, the DSM has undergone several iterations over the past two decades, suggesting that ADHD is indeed a "symptom complex" characterized by behaviors that are difficult to agree upon. In addition to DSM IV criteria, there are some diagnostic tools available to diagnose ADHD.

## Existing Tools for a Diagnosis of ADHD

According to DuPaul et al. (1991) the approach to diagnosis of ADHD may incorporates (1) parent and teacher interviews; (2) parent and teacher rating scales; (3) direct observations of behavior; and (4) academic record. There are certain objective tools such as continuous performance tests (CPTs) that are available to diagnose ADHD.

### *Rating Scales*

Rating scales which are most commonly used to diagnose ADHD are the parent-completed Child Behavior Checklist, the Teacher Report Form (TRF) of the Child Behavior Checklist, the Conners Parent and Teacher Rating Scales, the ADD-H: Comprehensive Teacher Rating Scale (ACTeRS), and the Barkley Home Situations Questionnaire and School Situations Questionnaire. These rating scales yield valuable information about overt symptoms efficiently. However, there are certain limitations in the use of rating scales in getting valid ratings. For example, factors like raters' identification with the ratees is one of the factor which may introduce bias and limit the effectiveness of rating scale. Often the rater is known / related to persons being rated. He may identify with some persons positively and with some persons negatively. Persons identified positively are likely to be rated high despite some unfavorable characteristics whereas persons identified negatively are likely to be rated low despite some favorable and sound characteristics. In both the situations the rating would be a misleading index and would reduce the effectiveness of the rating. Sometime vagueness in the meaning of the trait being rated may affect the rating negatively. For example, some traits or dimensions to be rated are vague and abstract ones. As a consequence, their meaning varies from rater to rater and thus naturally affects the consistency in ratings.

Most of the rating scales require the raters to rate the ratees in any one of different categories like superior, excellent, very good, or best, good, average, below average. When a rater rates a ratee as superior, the question arises as to what he standard is against which a ratee is being classified as superior. Is he being compared with the top 5% or top 10% or, is he being compared with he middle cases? The raters have no uniform standard before them so that the interpretation of category "superior" may not have an identical meaning to all. In the absence of a uniform standard, the interpretation of a category varies from rater to rater. One rater's "superior" may be another rater's simply "very good". This naturally lowers the consistency of ratings and thereby, their reliability. Raters' personal characteristics also tend to influence the ratings. Some raters are conservative and, therefore, they tend to rate persons almost in the middle. They rarely rate a person very high or very low. Some raters are tough and, therefore, rarely rate anybody high. Thus personal experiences of raters are likely to color their judgment and also their ratings. In such situations the rating done by one rater cannot be compared with the rating done by another rater. In addition, these subjective and behaviorally biased ratings do not objectively measure attentional variables, which are impaired in ADHD.

*Continuous Performance Tests (CPTs)*

Continuous Performance Tests (CPTs) are computer-based tests designed to measure inattention and impulsivity. It provides a quick assessment of current abilities for sustained attention. A number of CPTs are commercial available to private clinician for the assessment of children with ADHD: Gordon Diagnostic System (GDS) (Gordon, 1983), Test of Variables of Attention (TOVA) (Greenberg & Waldman, 1993), Conners' Continuous Performance Task (CCPT) (Conners, 1995), and the Intermediate Visual and

Auditory Continuous Performance Test (IVA) (Sandford, 1995). CPTs involve the presentation of stimuli that include a set number of predetermined targets to which subjects respond. CPTs vary in duration (a few minutes to half an hour), sensory modality (visual or auditory), stimuli (numbers, letters, drawings, and colors), and nature of the task (single target, double target, or sequential recognition). The differences among CPTs are factors to consider when comparing CPT performances. Most common measures assess omission errors, or misses, or commission errors, or false alarm and reaction time.

Two of the primary criticisms of the use of CPTs are discussed here. First is related to its reliability and validity; second, CPTs involve high rates of false negatives, and its limited ability to discriminate between ADHD and other clinical disorders.

The commercially available CPTs fail to report acceptable levels of test-retest reliability. The TOVA, for example, does not even report test-retest reliability, but rather, split-half reliability coefficients (Greenberg, 1996). Split-half reliability may be appropriate for a test that is given to a strong practice effect, but that is hardly true of the TOVA. Test-retest reliability is essential to consider in a test that is likely to be used serially (e.g., to evaluate an ADD patient’s response to stimulant medications). The Conners CPT-II reports test-retest reliability, but only on 23 participants, and not on raw scores, but on derived scores (Conners, 2000). The GDS lacks strong validity. It may be useful while conducting a comprehensive evaluation of children suspected of attentional problems. There are a number of important confounds that could affect the score obtained on GDS and other computerized measures. Wherry et al. (1993) investigated the validity of the GDS and the results were fairly poor. These authors stated that "The results failed to demonstrate the discriminant validity of any GDS score regardless of the behavior rating used." As Barkley and others (Barkley & Grodzinsky, 1994) have noted, in order for a test to be diagnostically useful, it must be able to not only identify the children with ADHD (sensitivity), but it must also accurately identify children without ADHD (specificity).

It is also necessary to investigate the sensitivity and specificity of the diagnostic measures. In the opinion of one expert panel (Dulcan & Popper, 1991) CPTs (Greenberg & Waldman, 1993; Barkley, 1990; Conners, 1985; Wigal et al., 1998) are not generally useful in diagnosis because they suffer from low specificity and sensitivity (Lovejoy & Rasmussen, 1990; Trommer et al., 1988). They are useful, however, as research tools. It is possible that CPTs may be useful in measuring some isolated symptoms of ADHD. Various CPTs have yielded false negative rates from 20 to 37% or higher (Greenberg & Waldman, 1993; Barkley, 1991), leading researchers to caution that "normal' CPT performance should not be used as evidence to rule out a diagnosis of ADHD. Rielly et al. (1999) used the GDS CPT to evaluate and classify children with a preschool history of language disorders for the presence of ADHD. They used the $5^{th}$ and $25^{th}$ percentiles as thresholds for 11 possible outcomes on three GDS tasks. For total commission errors from the vigilance portion of the CPT, sensitivity was 60% and specificity was 46% at the $5^{th}$ percentile; at the $25^{th}$ percentile these values were 88% and 23%, respectively (Table 1). The authots concluded that the GDS may have some clinical utility in ruling out a diagnosis of ADHD in children with a history of language disorders, but may not be sufficient to confirm an ADHD diagnosis in the population (Rielly et al., 1999). Description of the other CPTs and its sensitivity and specificity is presented in Table 1.

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In order to evaluate the efficacy of the CPT in the diagnosis of ADHD, it is important to consider if CPTs can help in discriminating ADHD from other co-morbid conditions. Children with ADHD are likely to have conduct disorder (CD), Oppositional Defiant Disorder (ODD) or Learning Disability (LD) (APA, 1994; Loney & Millich, 1982; Epstein et al., 1991). A diagnostic tool not only helps to differentiate ADHD from normal children (non-specific diagnosis), but also among disorders like CD, ODD and LD that tend to co-occur with ADHD (differential diagnosis). A number of studies have been found that CPTs have been inconsistent in differentiating ADHD from other clinical groups (Halperin et al., 1992).

One of the main reason that why CPTs are less able to discriminate ADHD from normal children and children with ODD/CD or LD is that CPT assess on aspect of attention such as sustained attention, which is impaired in ADHD. Indeed impairments, in sustained attention are common to a certain extent to all children with psychiatric disorders (Swaab-Barneveld et al., 2000). Therefore, it is important to asses those cognitive functions which are specifically impaired in ADHD and inculcate this information in the diagnostic system. This will provide a more sensitive as well as specific tool to tap the cognitive impairments in ADHD. Recent experimental literatures on ADHD have identified unique underlying cognitive dysfunction, specific to ADHD, are briefly discussed in the next section. In addition, few recent studies also demonstrate the differences in cognitive profile in ADHD subtypes (ADHD-combined type

(ADHD/CT) and ADHD-inattentive type (ADHD/IT) in terms of disinhibition (Nigg et al., 2002), and alerting and executive attentional network (Booth et al., 2001; Oberlin et al., 2005).

**Specific Cognitive Deficits in ADHD**

Recent experimental literature reveals that children with ADHD are characterized by specific deficits in the monitoring of attentional resources. These deficits in turn negatively affect the cognitive processes, such as response inhibition, error monitoring, attentional disengagement, (Logan, 1985; Rabbit, 1968; Schachar et al., 2004), decision making processes (Garon, 2006), and emotion regulation (Maedgen, 2000; Walcott, 2004).

There is evidence that the core deficit linked with ADHD involves sustained and selective attention that is necessary to perform a given task (Greenham, 1998). These individuals exhibit several deviations from their developmental level, sufficient to create impairments in major life activities. Most of these impairments have been studied using objective measures to demonstrate distinct attentional problems. The ADHD individuals show deficits in subsystems of attention such as alerting, orienting, and executive network. Some of the sustained attention problems among ADHD may also be linked with deficits in alerting mechanisms (Posner & Raichle, 1994), which are critical for normal cognitive functioning. Earlier work using spatial orienting task suggested that ADHD children have difficulty in maintaining an alert state (sustained attention) in the absence of warning signal (Swanson et al., 1991). More recent studies using the Attentional Network Task (ANT) have replicated problems with alerting in ADHD mainly due to the inability to maintain the alert state when no warning signal was used

(Blane & Marrocco, 2004; Booth et al., 2001). Other studies using task similar to ANT have also shown some evidence of abnormalities in alerting and/or executive control in ADHD in terms of slowed response times to abrupt visual cues especially when faced with conflicting spatial cues (Oberlin et al., 2005). It should be noted that impairment in attention processes also results in abnormal functioning in many higher order cognitive operations that involve inhibition of a pre-potent response, interference control and emotion regulation.

A number of studies provide consistent empirical support for the assumption that individuals with ADHD have a deficit in executive control processes, one of which is response inhibition (Barkley, 1997; Sergeant et al., 1999). Earlier studies reported that response inhibition deficits have also been associated with CD (Hurt & Naglieri, 1992; Oosterlaan et al., 1998). However, most previous studies have failed to control for comorbid diagnosis and it has been suggested that the association between disinhibition and CD might be accounted for by the large overlap with ADHD (Pennington & Ozonoff, 1996). On the other hand, it is also possible that the association between disinhibition and ADHD is caused by the overlap with CD. Finally, Lynam (1998) has argued that it is the combination of high levels of ADHD symptoms and conduct problems that is associated with poor inhibitory control, and this comorbid group has also been shown to have the most serious negative outcomes (Moffitt, 1990). Therefore, Nigg et al. (1998) suggested that it is very important to take into consideration that, even though children diagnosed with CD, may not meet the criteria for comorbid ADHD, they may still have considerably higher levels of ADHD symptoms compared to normal controls. As a consequence, it is important to treat data dimensionally, not categorically, and control for comorbid symptoms at a subclinical level (Nigg et al., 1998). Studies which have controlled for subclinical symptoms, reported that disinhibition is specific to ADHD and not primarily related to CD (Nigg et al., 1998 & Berlin & Bohlin, 2002). Berlin and Bohlin (2002) have reported that the correlation between response inhibition and conduct problems was no longer significant when controlling for hyperactivity, whereas the correlation between disinhibition and hyperactivity did remain significant when controlling for conduct problems. These findings indicate that the association between inhibition and conduct problems was caused by the large overlap between conduct problems and hyperactivity. It also provides further support for the role of response inhibition in understanding the mechanisms behind hyperactivity. A meta-analytic study also provides clear evidence for an inhibitory dysfunction in ADHD, whereas evidence for such a deficit for ODD/CD was less robust (Oosterlaan et al., 1998). ADHD is normally associated with slower responses during a stop signal task (Schachar & Logan, 1990) which requires responses to “go” trials and inhibition of responses during “no go” trials. Earlier, it was suggested that the ADHD individuals are deficient at monitoring responses during “no go” trials. However, meta-analytic results have shown potential milder problems during "go" responses as well, indicating that problems in response organization and arousal may also play a role in the disorder (Oosterlaan et al., 1998; Sergeant et al., 1999). More specifically, the impairments in executive control processes manifest as poor post error slowing and decrement in accuracy when faced with response conflict during a flanker task. Such deficits in monitoring ongoing behavior during the task were confirmed by the reduced event-related potential amplitude difference between correct and incorrect trials compared to normal controls (van Meel, 2007; Wang et al., 2004). Recent fMRI study indicates a functional anatomical asymmetry of response inhibition between ADHD and normal children.

Cognitive performance of individuals with ADHD is also characterized by large moment-to-moment fluctuations in cognitive control reflected by a highly inconsistent and inaccurate response style. It has been suggested that abnormal error processing underlies this failure to implement adequate control that provides top-down adjustment of elementary mental operations (Logan, 1985). ADHD individuals get slowed after fewer inhibition failures than normal controls and when they slow, they slowed to a lesser extent. This pattern of performance suggests that ADHD individuals differ from normally developing individuals in behavioral adjustment to errors. Another study examined error monitoring as one of the executive control measures being impaired in ADHD using the event related potential (ERP) methodology. The error-related negativity (ERN) was the same for ADHD and the control group, the former showed diminished error positivity (Pe). Based on these findings, the authors concluded that individuals with ADHD are normal in early error monitoring processes related to error detection as indexed by ERN. However, they show abnormal response strategy adjustments and are deviant in later error monitoring processes related to Pe which may also be associated with the subjective/emotional, conscious evaluation of the error (Leube et al., 2003). This is also an indication of the abnormal emotional regulation in these individuals. Yet in another study brain electrical activity was recorded during the stop signal task. Individuals with ADHD showed abnormal scalp distribution in P3a and reduce ERN in dorsal anterior cingulate cortex suggesting a global deficit in cognitive control operations in these individuals (Wiersema et al., 2005). ERP amplitude differences between correct and incorrect responses were also found to be diminished in ADHD. ADHD individuals also show larger deficit in control processes necessary for disengagement from one task and preparation for a subsequent task. It has been suggested that behavioral deficits observed in ADHD are a result of deficient resource allocation policies. No association has not been reported between error monitoring and reading disability, ODD/CD, or anxious behavior or generalized impairment (Schachar et al., 2004).

ADHD individuals are also characterized by the abnormality in reward responsivity that interferes with decision making. ADHD individuals are characterized by specific motivational style called "delay aversion" (Ernst et al., 2003). Delay aversion is the tendency to escape or avoid delay, results in preference for small immediate over large delayed rewards. This is again an indcation of abnormal emotional/motivational meachnism underlying ADHD. Recent positron emission tomography study suggested that neural circuits engaged during decision making differ in subjects with ADHD and healthy comparison subjects. Ventral and dorsolateral prefrontal cortex and the insula were activated during performance of the decision-making task in both the ADHD and healthy groups; however, activation in the ADHD group was less extended and did not involve other regions, such as anterior cingulate and hippocampus that sub serve emotion/memory processes. This difference may explain observed deficits in motivated behaviors in ADHD (Wu et al., 2006).

## Computerized Neurocognitive Diagnostic System based on Specific Cognitive Deficits: A Proposal

Diagnosis of ADHD has been dependent on clinician judgment. The existing tools available for the diagnosis of ADHD include rating scales (parents/teachers), clinical observations or CPTs. These tools are not susceptible enough to discriminate ADHD from other developmental disorder (differential diagnosis) as well as from normals. Experimental evidence informs about the cognitive mechanisms specific to ADHD. An objective assessment of cognitive impairments can explain the behavioral symptoms as well as could help in differential diagnosis. This is particularly important in the context of ADHD, as comorbidity is highly prevalent in ADHD. Therefore, we propose to develop a diagnostic system based on a combination of tests which tap specific cognitive deficits in ADHD in addition to the information about behavioral symptoms collected with other tools like rating scales and diagnostic criteria (DSM-IV). Such a diagnostic system will provide the clinician with objective data based upon the child's actual performance and will allow for observation in a paradigm likely to elicit inattention and impulsiveness. The clinical relevance of such a system will not only be limited to diagnosis but will also help to plan the treatment strategies including cognitive rehabilitation.

The rationale for using a more comprehensive neurocognitive screening battery is that ADHD is not simply a disorder of sustained attention. ADHD is marked by impairment in complex functional systems such as response inhibition, error monitoring, attentional disengagement, and decision making. Neuropsychological literature also indicates that although many tests show cognitive impairment in ADHD, no one test is sufficient to make the diagnosis of its own. ADHD patients are a diverse group; individuals may demonstrate deficits in one test, or in one cognitive domain, but not in another. Combinations of tests are more likely to yield useful information than any one single test (Konver et al., 1998; Doyle et al., 2000; Nigg et al., 2002; Schmitz et al., 2002; Gupta et al., 2006). CPTs like GDS, TOVA, CCPT, and IVA restrict the scope of the assessment of other cognitive impairments, such as response inhibition, error monitoring, and delay aversion that are specific to ADHD.

In addition, standardized, computer based laboratory measures of attention can provide objective data less influenced by factors such as rater bias. Computer based laboratory measures do offer both the researcher and clinician an opportunity to incorporate data derived from a child's actual behavior. It would also be helpful in order to detect attention problems in children who are not overtly hyperactive or impulsive (ADHD predominantly inattentive type) and might fall within the normal range on parent or teacher ratings of behavior.

**Empirical support for the above proposal**

We carried out a study (Gupta, Kar, & Srinivasan, manuscript under review) in which children with ADHD, ODD, and normal controls were examined on four tasks: Stop-signal task (SST), attentional disengagement task (ADT), attentional network task (ANT) (child version), and delay aversion task (DAT). In the SST required inhibition of a motor response. Stop-signal reaction time (SSRT), mean delay, and post-error slowing (PES) were the measure of this task. ADT required switching the attention from one task to another task (task-switching). All participants performed a task in which they had to respond to two different task rules, requiring to discriminating the value of a number presented on a computer screen and deciding how many numbers were present on the screen. Switch costs (SC; difference of RT between the switch trials and nonswitch trials) were the measure of this task. The child ANT is a complex task that provides a measure of efficiency of the atentional function of alerting, orienting, and executive control (Rueda et al., 2004). The ANT uses differences in reaction time (RT) between different conditions to measure the efficiency of each function. In the target display arrow of five fish presented either below or above fixation. Each target was preceded by one of four warning cue conditions: a center cue, a double cue, a spatial cue, or no cue. In the center cue condition, an asterisk is presented at the location of the fixation cross. In the double cue condition, an asterisk appears at the locations of the target above and below the fixation cross. Spatial cues involve a single asterisk presented in the position of the upcoming target. Children are instructed to pay attention to the middle fish, and to respond based on whether it is pointing to left or right by pressing the corresponding key. In the executive attention children are presented with fish surrounded by congruent and incongruent flankers. Differences in RT between incongruent trials and congruent trials give the score of executive attention. Differences in RT between nocue condition and double cue give the score of alerting function. Differences in RT between center cue and spatial cue give the score of orienting function. Alerting, orienting, and conflict score were the measure of this task. In the delay aversion task participants were required to choose between a small rewards (1 point) delivered after a short delay (1 second) or a large reward (2 points) delivered after a long delay (20 seconds). Thus, the child could choose between a small, immediate reward (SDR) and a large, delayed reward (LDR). %LDR and %SDR were the measure of this task.

We obtained the Receiver Operating Characteristic (ROC) for each parameter of each task to calculate the sensitivity and specificity to see which parameters individually classify the participants with their respective group correctly. Effect size of the parameters such as %LDR (or %SDR), SC, SSRT, PES, mean delay, and grand mean was more with the range of (0.49 to 0.66) as compared to other parameters such as alerting, orienting, and conflict score with the range of 0.033 to 0.004. Therefore, in the further analysis only these six parameters were combined through multinomial logistic regression to determine which parameters together can classify the children in their respective group correctly. Overall percentage of the correct classification of the individual seven parameters was 64%-72%. These parameters were then combined with multinomial logistic regression. We have tried all the possible combinations of the parameters. By combining any of the two parameters overall correct classification was 72%-87 %. By combining three it was 82%-92%, by four it was 89%-95%, by five it was 96%-98%, by six it was 97%-98%, and by seven the overall percentage of the correct classification was increased to 97%. Together all the six parameters correctly classified 97.8% of the participants, with ADHD children classified correctly 100%, ODD children 100%, and control with 93.3%. This study indicates that cognitive mechanisms underlying ADHD such as response inhibition, error monitoring, attentional disengagement, delay aversion were together not only helpful in diagnosis of children with ADHD rather it also helpful in differential diagnosis. Thus, these cognitive markers should be incorporate in the diagnostic system, which will provide sensitive and specific tool to tap the cognitive impairments, which may help in differential diagnosis.

**Conclusion**

Diagnosis of a disorder like ADHD is a complex issue for a clinician because of the high prevalence of co-morbid conditions. Misdiagnoses is likely to happen which may in turn affect the treatment. Reasons for misdiagnosis are due to the dependence on subjective reports based on rating scales, interviews from parents while arriving at a diagnostic decision. The subjective reports yield valuable information efficiently and systematically. However, there are some factors, which limit or affect valid ratings such as “rater bias”. Children with ADHD often show strong associations with disorders such as anxiety, depression, conduct disorder (CD), Tourette’s syndrome (TS) and oppositional defiant disorder (ODD) (Angold et al., 1999). Furthermore, ADHD, particularly the inattentive symptoms, are also associated with reading disability (Maedgen, 2000). Therefore, differential diagnosis is especially important in ADHD due to both the frequent co-occurrence of ADHD with other disorders and to the potential for other symptoms to produce symptoms that overlap with the behavioral criteria for ADHD. Recent experimental literature has identified cognitive mechanisms underlying ADHD. Thus, there is need to incorporate information on cognitive mechanisms underlying ADHD and inculcate such information in the diagnostic system, which will provide a more sensitive as well as specific tool to tap the cognitive impairments, which may help in differential diagnosis. Such a diagnostic system will provide the clinician with objective data based upon the child’s actual performance and will allow for observation in a paradigm likely to elicit inattention and impulsiveness. Moreover, multiple sources of information, both subjective and objective need to be incorporated in the diagnostic procedure to ensure accurate diagnosis of ADHD.

**Table Legends**

Table 1. Description of various CPTs and its sensitivity and specificity.

| Existing measures to assess cognitive impairments in ADHD | Description | Sensitivity (%) | Specificity (%) |
|---|---|---|---|
| Gordon Diagnostic System [9] | GDS is a self-contained portable unit, which administers two attention tasks and a test of impulse control. It consists of three subtests, Delay, Vigilance, and Distractibility | 60 at $5^{th}$ percentile<br>88 at $25^{th}$ percentile | 46 at $5^{th}$ percentile<br>23 at $25^{th}$ percentile |
| Test of Variables of Attention [13] | The TOVA (auditory and visual) was designed for use in diagnosis and monitoring medication effectiveness in children and adults with attention | 80 (1 > 1.5 SD[a])<br>52 (2 > 1.5 SD)<br>13 (3 > 1.5 SD)<br>67 (2 > 1.0 SD) | 72 (1 > 1.5 SD[a])<br>90 (2 > 1.5 SD)<br>100 (3 > 1.5 SD)<br>86 (2 > 1.0 SD) |

| | | | |
|---|---|---|---|
| | deficit disorders | | |
| Conners' Continuous Performance Task [11] | CCPT is a vigilance task in which respondents are asked to press a button when any letter but "X" appears on the screen | 50 | 50 |
| Intermediate Visual and Auditory Continuous Performance Test [12, 67] | The IVA is an integrated 13-minute auditory and visual CPT. In addition to the typical demands of clicking in response to a designated target, the IVA requires the test taker to "shift sets" and to make discriminatory responses to mixed auditory and visual stimuli | 70 | 64 |

## References


American Psychiatric Association (APA) (1994). Task force on DSM-IV. Diagnostic and statistical manual of mental disorders, Fourth Edition. Washington DC: American Psychiatric Press.

Angold, A., Costello, E. J., & Erkanli, A. (1999). Comorbidity. *Journal of Child Psychology and Psychiatry, 40,* 57-87.

Barkley, R. A. & Grodzinsky, G. M. (1994). Are test of frontal lobe function useful in the diagnosis of ADD. *Clinical Neuropsychology, 8*, 121-139.

Barkley, R. A. (1990). Attention Deficit Hyperactivity Disorder: A Handbook for Diagnosis and Treatment. New York: Guildford Press.

Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessment of ADHD symptoms. *Journal of Abnormal and Child Psychology, 19, 1*49-178.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of AD/HD. *Psychological Bulletin, 121*, 65-94.

Barkley, R. A. (1998). Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment, Second Edition. New York: Guildford Press.

Berlin, L. & Bohlin, G. (2002). Response Inhibition, Hyperactivity, and Conduct Problems among Preschool Children. *Journal of Clinical and Child Psychology, 31*, 242-251.

Blane, M. & Marrocco, R. (2004). Cholinergic and Noradrenergic inputs to the posterior parietal cortex modulate the components of exogenous attention. In M.I. Posner (Ed.), Cognitive neuroscience of attention New York: Guilford. pp. 313-325.

Booth, J., Carlson, C. L., & Tucker, D. (2001). Cognitive inattention in the ADHD subtypes. Paper presented in the 10th meeting of the International Society for Research in Child and Adolescent Psychopathology, Vancouver, Canada.

Conners, C. K. (1985). The computerized continuous performance test. *Psychopharmacology Bulletin, 21,* 891-892.

Conners, C. K. (2000). Conners' CPT II for windows. North Tonowada, NY: Multihealth System.

Conners, K. (1995). Conners' Continuous Performance Test Computer Program 3.0: Users Manual. Canada: Muli-Health Systems, Inc.

Doyle, A. E., Biederman, J., Seidman, L. J., et al. (2000). Diagnostic efficiency of neuropsychological test scores for discriminating boys with and without attention deficit-hyperactivity disorder. *Journal of Consulting and Clinical Psychology, 68, 4*77-488.

Dulcan, M. & Popper, C. (1991). Concise guide to child and adolescent psychiatry. Washington, DC.

DuPaul, G. J., Guevremont, D. C., & Barkley, R. A. (1991). Attention Deficit-Hyperactivity Disorder in adolescence: Critical assessment parameters. *Clinical Psychology Review, 11,* 231-245.

Epstein, M. A., Shaywitz, S. E., Shaywitz, B. A., & Woolston, J. L. (1991). The boundaries of attention deficit disorder. *Journal of Learning Disability, 24,* 78-86.

Ernst, M., Kimes, A. S., London, E. D., Matochik, J. A., Eldreth, D., Tata, S., Contoreggi, C., Leff, M., & Bolla, K. (2003). Neural Substrates of Decision

Making in Adults with Attention Deficit Hyperactivity Disorder. *American Journal of Psychiatry, 160,* 1061-1070.

Garon, N. (2006). Decision Making in Children with ADHD Only, ADHD-Anxious/Depressed, and Control Children Using a Child Version of the Iowa Gambling Task. *Journal of Attentioanl Disorder, 9,* 607-619.

Gordon, M. (1983). The Gordon Diagnostic System. Dewitt, NY: Gordon Systems.

Greenberg, L. M. & Waldman, I. D. (1993). Developmental normative data on the test of variables of attention (T.O.V.A.). *Journal of Child Psychology and Psychiatry, 34,* 1019-1030.

Greenberg, L. M. (1996). Test of Variables of Attention: Professional Manual (Version 7.0). Los Alamitos, CA: Universal Attention Disorders.

Greenham, S. L. (1998). Attention-deficit hyperactivity disorder and event-related potentials: evidence for deficits in allocating attentional resources to relevant stimuli. *Child Neuropsychology, 4,* 67-80.

Gupta, R., Kar, B.R., & Srinivasan, N. Cognitive Markers of ADHD: Development of a diagnostic system (manuscript under review).

Gupta, R., Kar, B. R., & Thapa, K. (2006). Specific Cognitive Dysfunction in ADHD: An Overview. In J. Mukherjee & V. Prakash (Ed.), *Recent Developments in Psychology* (pp. 153-170). Delhi.

Halperin, J. M., Mattier, K., Bedi, G., Sharma, V., & Newcorn, J. H. (1992). Specificity of inattention, impulsivity and hyperactivity to the diagnosis of attention-deficit hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 38,* 190-196.

Hurt, J. & Naglieri, J. A. (1992). Performance of delinquent and nondelinquent males on planning, attention, simultaneous, and successive cognitive processing tasks. *Journal of Clinical Psychology, 48,* 120-128.

Konver, R., Budman, C., Frank, Y., et al. (1998). Neuropsychological testing in adult attention deficit hyperactivity disorder: A pilot study. *International Journal of Neuroscience, 96,* 225-235.

Lambert, N. M., Sandoval, J., & Sassone, D. (1973). Prevalence of hyperactivity in elementary school children as a function of social system definers. *American Journal of Orthopsychiatry, 48,* 446-63.

Leube, D T., Knoblich, G., Erb, M., Grodd, W., Bartels, M., & Kircher, T. T. (2003). The neural correlates of perceiving one's own movements. *Neuroimage, 20,* 2084-2090.

Logan, G. D. (1985). On the ability to inhibit simple thought and action II. Stop signal studies of repetition priming. *Journal of Experimental Psychology, 2,* 675-691.

Loney, J. & Millich, R. (1982). Hyperactivity, inattention, and aggression in clinical practice. In: Wolraich M, Routh, D (eds). Advances in developmental behavior pediatrics. Greenwich (CT): JAI Press.

Lovejoy, M. C. & Rasmussen, N. H. (1990). The validity of vigilance tasks in differential diagnosis of children referred for attention and learning problems. *Journal of Abnormal Child Psychology, 18,* 671-681.

Lynam, D. R. (1998). Early identification of the fledgling psychopath: locating the psychopathic child in the current nomenclature. *Journal of Abnormal Psychology, 107,* 566-575.

Maedgen, J. W. (2000). Social Functioning and Emotional Regulation in the Attention Deficit Hyperactivity Disorder Subtypes. *Journal of Clinical Child Psychology, 29,* 30-42.

Moffitt, T. E. (1990). Juvenile delinquency and attention deficit disorder: Boys' developmental trajectories from age 3 to age 15. *Child Development, 61,* 893-910.

Nigg, J. T., Hinshaw, S. P., Carter, E. T., & Treuting, J. J. (1998). Neuropsychological correlates of childhood attention-deficit/hyperactivity disorder: Explainable by comorbid disruptive behavior or reading problems? *Journal of Abnormal Psychology, 107,* 468-480.

Nigg, J. T., John, O. P., Blaskey, L G., Huang-Pollock, C.L., Willcutt, E.G., Hinshaw, S.P., & Pennington, B. (2002). Big five dimensions and ADHD symptoms: Links between personality traits and clinical symptoms. *Journal of Personality and Social Psychology, 83,* 451–469.

Oberlin, B. G., Alford, J. L., & Marrocco, R. T. (2005). Normal attention orienting but abnormal stimulus alerting and conflict effect in combined subtype of ADHD. *Behavior and Brain Research, 165,* 1-11.

Oosterlaan, J., Logan, G. D., & Sergeant, J. A. (1998). Response inhibition in AD/HD, CD, comorbid AD/HD+CD, anxious and control children: a meta-analysis of studies with the stop task. *Journal of Child Psychology and Psychiatry, 39*, 411-426.

Pennington, B. F. & Ozonoff, S. (1996). Executive functions and development of psychopathology. *Journal of Child Psychology and Psychiatry Allied Discipline, 49,* 51-87.

Posner, M., & Raichle, M. (1994). Images of mind. New York: Scientific American Library.

Rabbit, P. M. (1968). Three kinds of error-signaling responses in a serial choice task. *Quarterly Journal of Experimental Psychology, 20*, 179-188.

Rielly, N. E., Cunningham, C. E., Richards, J. E., et al. (1999). Detecting attention deficit hyperactivity disorder in a communications clinic: Diagnostic utility of the Gordon Diagnostic System. *Journal of Clinical and Experimental Neuropsychology, 23*, 685-700.

Rueda, M. r., Fan, j., McCandliss, B. D., Halparin, J. D., Gruber, d. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. Neuropsychologia, *42*, 1029-1040.

Sandberg, S. T., Wieselberg, M., & Shaffer, D. (1980). Hyperkinetic and conduct problem children in a primary school population: some epidemiological considerations. *Journal of Child Psychology and Psychiatry, 21,* 293-311.

Sandford, J. A. (1995). Intermediate Visual and Auditory Continuous Performance Test: Administration and Interpretation Manual (Version 1.2). Richmond, VA: Brain Train.

Schachar, R. 7 Logan, G. (1990). Are hyperactive children deficient in attentional capacity? *Journal of Abnormal Child Psychology, 18,* 493-513.

Schachar, R., Chen, S., Logan, G. D., Ornstein, T. J., Crosbie, J., Ickowicz, A., & Pakulak, A. (2004). Evidence for an error monitoring deficit in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology, 18,* 285-293.

Schmitz, M., Cadore, L., Paczko, M., et al. (2002). Neuropsychological performance in DSM-IV ADHD subtypes: An exploratory study with untreated adolescents. *Canadian Journal of Psychiatry, 47,* 863–869.

Sergeant, J. A., Oosterlaan, J. & van der Meere, J. (1999). Information processing and energetic factors in attention-deficit/hyperactivity disorder. In H. C. Quay & A. E. Hogan (Eds.), Handbook of disruptive behavior disorders. New York: Kluwer Academic/Plenum. pp. 75-104.

Swaab-Barneveld, H., de, S. L., Cohen-Kettenis, P., et al. (2000). Visual sustained attention in a child psychiatric population. *Journal of the American Academy of Child and Adolescent Psychiatry, 39,* 651-659.

Swanson, J. M., Posner, M. I., Potkin, S., Bonforte, S., Youpa, D., Cantwell, D., & Crinella, F. (1991). Activating tasks for the study of visual-spatial attention in ADHD children: A cognitive neuroanatomical approach. *Journal of Child Neurology, 6S,* S119-S127.

Trommer, B. L., Hoeppner, J. B., Lorber, R., & Armstrong, K. (1988). Pitfalls in the use of a continuous performance test as a diagnostic tool in attention deficit disorder. *Journal of Developmental and Behavioral Pediatric, 9,* 339-345.

van Meel, C. S., Heslenfeld, D. J., Oosterlaan, J., & Sergeant, J. A. (2007). Adaptive control deficits in attention-deficit/hyperactivity disorder (ADHD): the role of error processing. *Psychiatry Research, 151,* 211-20.

Walcott, C. M. (2004). The Relation between Disinhibition and Emotion Regulation in Boys with Attention Deficit Hyperactivity Disorder. *Journal of Clinical and Child Adolescent Psychology, 33,* 772-782.

Wang, B., Sui, M. Q., Wang, Y. F., & Fan, J. (2004). A preliminary study on the attentional networks of attention deficit hyperactivity disorder. *Beijing Da Xue Xue Bao, 85*, 370-373.

Weinberg, W. A. & Harper, C. R. (1993). Vigilance and its disorders. *Neurologic Clinics, 11,* 59-78.

Weinberg, W. A., Brumback, R. A. (1992). The myth of attention deficit-hyperactivity disorder: symptoms resulting from multiple causes. *Journal of Child Neurology, 7,* 431-445.

Wherry, J. N., Paal, N., Jolly, J. B., Balkozar, A., Holloway, C., Everett, B., & Vaught, L. (1993). Concurrent and discriminant validity of the Gordon Diagnostic System: A preliminary study. *Psychology in the Schools, 1*, 29-36.

Wiersema, J. R., van der Meere, J. J. & Roeyers, H. (2005). ERP correlates of impaired error monitoring in children with ADHD. *Journal of Neural Transmission, 112,* 1417-30.

Wigal, S. B., Gupta, S., Guinta, D., & Swanson, J. M. (1998). Reliability and validity of the SKAMP rating scale in a laboratory school setting. *Psychopharmacol Bulletin, 34,* 47-53.

Wu, K. K., Anderson, V., & Castiello, U. (2006). Attention-Deficit/Hyperactivity Disorder and working memory: a task switching paradigm *Journal of Clinical and Experimental Neuropsychology, 28,* 1288-306.