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Differential assessment of attention and its relationship to behavior problems in children

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DIFFERENTIAL ASSESSMENT OF ATTENTION AND ITS RELATIONSHIP TO BEHAVIOR PROBLEMS IN CHILDREN

by

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A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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Abstract

DIFFERENTIAL ASSESSMENT OF ATTENTION AND ITS RELATIONSHIP TO BEHAVIOR DISORDERS IN CHILDREN

by

Lorraine E. Wolf

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The present research was designed to help clarify the role of attention and behavioral control in children, and to improve attentional measurement. Experiment 1 utilized several common tests to explore the separation of attentional subprocesses in hyperactive and normal children. Seventy-two nonreferred school children were given a test battery consisting of the continuous performance test (CPT), Peabody Picture Vocabulary Test, Matching Familiar Figures and Digit Span tests. Children were rated by their teachers using the Revised Conners Teacher Questionnaire (CTQ). A Principal Components Factor analysis of CPT, attentional and cognitive test scores yielded a four factor solution. Two of these conformed to predictions of distinct CPT measures of speed/consistency or "sustained attention" (made up of reaction time and RT variability), and accuracy or

"behavioral control" (false alarms). The behavioral control factor, but not the sustained attention factor, was related to behavior problems, as rated by teachers. This suggests that the CPT may be sensitive to at least two distinct aspects of vigilance performance that might be differentially affected in normal and behavior disordered children. The notion of a unitary "attention deficit" is challenged by the finding of distinct attentional subcomponents.

Experiment 2 examined sustained attention by looking at speed and accuracy changes on the CPT over time. A new group of 72 children were divided into hyperactive and nonhyperactive groups using the CTQ. Mean CPT variables measured across the duration of the task failed to distinguish the groups. However, systematic, group specific decrements in speed and accuracy over time were found to characterize the hyperactive group. This vigilance decrement may be due to failures to make strategy adjustments with time on task.

Additional findings were that regardless of teacher rating, children with the fastest mean hit RTs made the most impulsive false alarms. Inattentive errors were associated with slow mean RTs. Age control in analysis of CPT data is stressed, and the point is made that behavioral control may more pertinent in the vigilance performance of children than adults.

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INTRODUCTION

Attempts to understand the role of attention in childhood psychiatric disorders and to develop improved methods of assessment and classification have been complicated by diagnostic, methodological, and theoretical problems. Attention has proven to be a difficult concept; hard to define and often harder to measure. Although we believe we know what we mean when we refer to "attention" and "attention disorder", a review of the literature as well as more casual observation of the ways in which the term is used suggests that this may not be the case.

Models of attention have consistently failed to account for all of the findings (Hirst, 1986; Broadbent, 1971). The failure of early unitary models led to the development of bipartite models (e.g. selective versus sustained attention, or controlled versus automatic processing), which themselves break down into further subtypes. Depending on the model, attention may or may not be innate, affected by learning or motivation, or subject to development or change over time. There is no definitive model of "attention" and to a large degree, what is hypothesized may depend upon what is measured.

Attentional measurement involves a variety of instruments which often yield inconsistent results. These inconsistencies may be due in part to the fact that various assessment instruments evaluate different aspects of attention. In addition, many workers use measures of attention which lack construct validity. There has been relatively little investigation of the relationships and overlap between these instruments. Indeed, it is often unclear which psychological processes are being assessed by each, let alone whether or not they measure similar or different processes. These difficulties certainly complicate the clinical assessment of attention.

Despite this complication, such instruments form the core of the psychological assessment of attention in children. They were important tools in the diagnostic reformulation of Hyperkinetic Reaction of Childhood as a disorder of attention.

Reclassification notwithstanding, Attention Deficit Hyperactivity Disorder (ADHD) is comprised of multiple symptoms, including inattention, impulsivity and excessive motor activity (APA DSM-III-R, 1988). There is considerable symptom overlap between "distinct" diagnostic groups, which contributes to the lack of agreement as to the nature of the process which is presumed to be aberrant in ADHD.

The major focus of this dissertation is to further understand the role of attention and behavioral control in childhood behavior disorders, and to try to develop improved means of assessing problems in those areas. There are many unsatisfactory models of adult attention, and many of the most popular instruments in child assessment were developed specifically to assess attention in adults based upon these models. Studies have not examined whether scaled down versions of adult tasks are appropriate for children, or whether there is something unique about the ways in which children approach such tasks.

In addition, insufficient effort has been put into examining attentional processes in children as a function of measurement. The reconciliation of certain childhood diagnostic and measurement difficulties may hinge on more process (as opposed to symptom) oriented approaches to classification of behavior disorders, utilizing developmentally appropriate models and measures. The first step towards developing these models is to understand what processes might be involved in childhood attention, and to investigate how these processes may be explained by the existing adult models. This was the goal of the following studies.

Attention Deficit/Hyperactivity Disorder

Attention Deficit/Hyperactivity Disorder (ADHD) is a common disorder of childhood, making up 30 to 40 percent of referrals to child mental health clinics (Safer & Allen, 1976). ADHD is characterized by some combination of inattention, impulsivity and excessive motor activity (APA, 1987). It is frequently associated with low frustration tolerance and distractibility (Douglas, 1972; Douglas & Peters, 1979; Rapoport, Tucker, DuPaul, Merlo & Stone, 1986), poor academic performance (Cantwell & Satterfield, 1978), poor social relations (King & Young, 1981; Milich & Landau, 1982), low self esteem and other emotional difficulties (Weiss & Hechtman, 1986), aggressivity and conduct problems (Milich, Loney & Landau, 1982; Thorley, 1984; Mash & Johnston, 1982) in children of normal intelligence (APA, 1987; Barkley, 1982). Children with ADHD have more of these difficulties than siblings or matched controls (Ross & Ross, 1982).

Prevalence estimates have ranged from 5 to 20 percent (Sprague, Christensen & Werry, 1974; Trites, Dugas, Lynch & Ferguson, 1979)), although current estimates are of significant ADHD symptoms in 3-5 percent of school age children in this country (Lambert, Sandoval & Sasone, 1981). Due to its high prevalence in the school population and the severity of the emotional and behavioral problems associated with it, ADHD is a significant clinical and educational concern.

ADHD becomes apparent during the earliest years of life. Many parents report that their children were cranky and overactive, slept or ate poorly as infants (Weiss & Hechtman, 1979). The disorder is usually diagnosed during the early school years, as the inappropriate and often disorganized motor activity and poor attention span characteristic of the ADHD child become apparent to teachers and other school personnel. Ninety-five percent of children diagnosed as hyperactive* present with symptoms before age 7 years (Barkley, Fischer, Newby & Breen, 1988; Weiss & Hechtman, 1986). The disorder is more common in boys than girls, with a gender distribution of 4:1 to 8:1 (Barkley, 1987; Holborow, Berry & Elkins, 1984). Symptoms vary in different settings and situations, with only a small percentage of children presenting as pervasively hyperactive (Schachar, Rutter & Smith, 1981; Taylor, 1983). Increased environmental demands for attention and sustained effort to tasks which are dull or repetitive result in escalation of the symptoms of hyperactivity, inattention and impulsivity (Douglas, 1983; van Der Meere & Sergeant, 1988a).

* The terms "hyperactive" and "ADHD" will be used interchangeably in this discussion.

Many hyperactive children respond favorably to treatment with stimulant medication, which appears to relieve motor overactivity, and ameliorate inattention and distractibility (Barkley & Cunningham, 1978; Dykman, Ackerman & McCray, 1980; Sykes, Douglas, Weiss & Minde, 1971; Campbell, Douglas & Morgenstern, 1971). However, there is no evidence that even successful stimulant treatment improves academic achievement (Barkley & Cunningham, 1978) or long term outcome (Loney, Kramer & Milich, 1981; Weiss & Hechtman, 1986). While many hyperactive children appear to outgrow the motor symptoms associated with the disorder, cognitive and social difficulties persist into adolescence, rendering them vulnerable to learning difficulties and psychopathology in later life (Loney, Kramer & Milich, 1981; Gittelman, Mannuzza, Shenker & Bonagura, 1985). Approximately one third of hyperactive children retain significant symptoms of the disorder into adulthood (Gittelman et al., 1985; Weiss & Hechtman, 1986). Moreover, adolescents with unremitted ADHD symptoms are at high risk for the development of antisocial behavior, conduct problems (Hechtman, Weiss, Perlman & Amsel, 1984; Gittelman et al., 1985) and substance abuse as adults (Gittelman et al., 1985).

There is frequent comorbidity of ADHD with Oppositional Disorder (Shapiro & Garfinkel, 1986; Munir, Biederman & Knee, 1987), Specific Developmental Disabilities (McGee & Share, 1988) and Conduct Disorder (Shapiro & Garfinkel, 1986; Biederman, Munir & Knee, 1987). Family and genetic studies have shown an increased incidence of ADHD, learning problems and psychopathology in the biological relatives of hyperactives (Cantwell, 1972; Cantwell, 1975; Biederman, et al., 1987).

Early descriptions of ADHD focussed on excess motor activity as the core deficit of the disorder. The second edition of the Diagnostic & Statistical Manual called the disorder "Hyperkinetic Reaction of Childhood" and stressed abnormally high levels of motor activity as the primary deficit. ADHD has alternately been referred to as Minimal Brain Dysfunction (or Damage), hyperkinesis and hyperactivity. The label "minimal brain dysfunction" reflects the growing awareness in the field that cognitive and behavioral disturbances in childhood might reflect organic brain damage or more subtle CNS dysfunctions. Some clinicians observed hyperkinesis as a sequelae of head injury or encephalitis in children (Wender, 1972). This finding and the presence increased neurological "soft signs", such as clumsiness and impaired fine motor coordination, and minor EEG abnormalities (Wender, 1972; Wender, 1975; Ferguson & Rapoport, 1983) reinforced the view that hyperactivity might result from brain damage. Yet, no study has demonstrated clear evidence of overt CNS dysfunction in ADHD children (Halperin, Gittelman, Katz, & Strove, 1986), nor is there evidence for a focal CNS lesion responsible for hyperactivity (Ferguson & Rapoport, 1983).

Failure to find evidence of focal CNS disturbance in hyperactivity led clinicians to other formulations of the disorder. The dramatic response of many hyperactives to stimulant medication led workers to hypothesize more diffuse biochemical lesions and arousal differences which might better account for the disorder. The shift in the nomenclature from "Hyperkinetic Reaction " to "Attention Deficit Disorder with (and without) Hyperactivity" (APA, 1980) and most recently "Attention Deficit/ Hyperactivity Disorder" (APA, 1987) reflects the changing view that motor activity may not be the core deficit in the disorder.

Rather than excessive motor activity, the problem may be one of inappropriate and disorganized motor activity. In fact, the hyperactive child may be indistinguishable from classmates in unstructured free play (Weiss & Hechtman, 1979; Zentall, 1980), and only demonstrate difficulty in structured and attention demanding activities, such as encountered in the classroom. Frequent behavioral and attentional lapses, shifts from one activity to another with no regard for goals, impulsivity and disinhibited behaviors such as not waiting his/her turn are more descriptive of the behavior of ADHD children than overactivity. Furthermore, parents often note that their hyperactive child is perfectly capable of sitting still when it suits him/her. Only a small percentage are in fact pervasively hyperactive (Schachar, Rutter & Smith, 1981; van der Meere & Sergeant, 1988a; van der Meere & Sergeant, 1987). Therefore, while there is still debate about the issue of hyperactivity-as-core-symptom (Porrino, Rapoport, Behar, et al., 1983) most recent formulations have moved from the behavioral realm to an attentional and cognitive one.

Behavioral and Cognitive Deficits Associated with ADHD

Douglas (1983) has grouped the many cognitive deficits proposed to underlay ADHD into four areas. In her formulation, hyperactive children can be seen as having primary difficulties in the areas of arousal, inhibition, attention and response to reinforcement. Inability to modulate attention and arousal levels commensurate with situational demands, or to withhold inappropriate responses to presumably distracting situations, and inappropriate or deficient responses to positive and negative reinforcement characterizes the performance of hyperactive children on a wide range of laboratory, cognitive, academic and social tasks (Douglas & Peters, 1979; Douglas, 1983). These problems are most pronounced in situations which require sustained, reflective and focussed effort (Douglas, 1983).

The four main cognitive symptoms are seen as aspects of a core predisposed disorder (Douglas & Peters, 1979).

The other associated features of ADHD are seen as secondary to the basic problems outlined above. The rest of this section will proceed according to the assumption that the cognitive difficulties of hyperactive children may be grouped into arousal, inhibition and attention. Response to reinforcement will not be included in this discussion.

Arousal and ADHD

There are many different definitions of arousal and many different ways to measure it. Arousal is generally taken to refer to a generalized preparedness to respond to some environmental stimulus or event. It is a construct which is indirectly observed through behavioral and psychophysiological measures. Arousal is operationally as well as intuitively tied to activity and attention. The difficulties of hyperactive children in these areas suggested to many authors that the basic defect was one of arousal.

Some have measured arousal in terms of activity level (Rosenthal & Allen, 1978; Sykes, Douglas & Morgenstern, 1972; Sroufe, Sonies, West & Wright, 1973; Sprague & Toppe, 1966; Barkley & Jackson, 1977; Solanto & Conners, 1982) and reaction time (Sykes et al., 1971, 1972; Firestone & Douglas, 1975; Sroufe et al., 1973). Others have utilized autonomic and psychophysiological signs such as heart rate (Zahn, Abate, Little & Wender, 1975; Sroufe, et al., 1973), skin conductance (Firestone & Douglas, 1975; Cohen & Douglas, 1972; Satterfield & Dawson, 1971; Satterfield, Lesser, Saul & Cantwell, 1973; Raskin, 1973), EEG (Satterfield, Cantwell, Saul, et al., 1973; Satterfield, Cantwell, Saul & Yusin, 1974; Satterfield & Dawson, 1971) and evoked potential (EP) (Satterfield, et al., 1973; Buchsbaum & Wender, 1973; Hall, Griffin, Moyer, et al., 1976; Callaway, Halliday & Naylor, 1983; Loiselle, Stamm, Matinsky & Whipple, 1980).

Much confusion has resulted from the use of such a wide array of measures. Some authors have posited that hyperactives are overaroused (Laufer, Denhoff & Solomans, 1957) while others believe hyperactives to be underaroused (Satterfield, 1976; Satterfield, Cantwell, Lesser & Podosin, 1972; Satterfield & Dawson, 1971). More recently, it has been suggested that there is an inverted U-shaped function which describes arousal, wherein difficulties at either extreme disrupt performance and behavior (Zentall, 1983; Zentall & Zentall, 1976; Wender, 1972; Posner, 1982). In this view, hyperactives are seen to operate somewhere out of the optimal range of arousal (Douglas, 1983). Although behavioral arousal correlates well with physiological arousal, it has been suggested that the term "activity" be used to refer to the former while "arousal" be reserved for the latter (Rosenthal & Allen, 1978).

Behavioral Studies of Arousal

Overactivity. Despite disagreement as to the role of hyperactive behavior in the diagnostic classification of ADHD, it is generally agreed than hyperactive children display excessive or inappropriate levels of motor activity (Porrino et al., 1982). Many authors have interpreted this behavior as a sign of behavioral overarousal (Wender, 1975).

Objective assessment of motor activity has generally proven difficult, as instruments are diverse and often unreliable (Douglas, 1983). Moreover, the various measures of activity do not correlate well with each other, thus comparison between studies is difficult (Rosenthal & Allen, 1978). Pope (1970) utilized the ankle accelerometer to compare unstructured playroom activity of hyperactive versus normal children. He concluded that hyperactives exhibit more activity during both unstructured and structured, difficult tasks. Measuring seat restlessness with a stabilometric cushion, Sykes and colleagues (Sykes et al., 1971; Sykes, Douglas & Morgenstern, 1972) demonstrated that hyperactives are more restless than normals during reaction time and vigilance tasks. This led them to assert that increased activity is secondary to decreased attention, and that stimulants reduce activity in hyperactives by increasing attention (Sykes et al., 1972; Rosenthal & Allen, 1978). Barkley & Jackson (1977) demonstrated that hyperactives are more active on many measures (wrist and ankle accelerometers, stabilometric cushion and floor grids which measure room activity) during unstructured play, structured play, and while watching movies. Drugs reduced activity relative to placebo on all measures in all settings, with the exception of seat activity during structured testing (Barkley, 1977). Solanto & Conners (1982) found that stimulant medication reduced seat activity during testing and at rest. They concluded that this was not due to the enhancement of attention by the medication.

Low doses of stimulants have been widely reported to affect brain centers involved in regulation of states of arousal. They are reported to result in an alerting or activating response (Julien, 1981). Several studies have shown that stimulant medication <u>reduces</u> motor activity in hyperactives (Sroufe et al., 1973; Rapoport, Abramson, Alexander & Lott, 1971) however one study showed that amphetamines <u>increase</u> motor activity (Witt, Ellis & Sprague, 1970). It is generally agreed, however, that hyperactives are more active than normals across a wide range of structured and unstructured situations, and that stimulants in part operate to reduce this activity (Solanto, 1984).

<u>Reaction Time Measures</u>. Premature, incorrect or repetitive motor responses during reaction time (RT) and

vigilance tests may be used to index motor impulsivity, decreased motor control and arousal. Latency of response to signals has been used as a measure of attention and arousal (Posner & Boise, 1971). Hyperactive children have been shown to commit more erroneous responses on choice and serial RT tasks, and to have slower and more variable RTs relative to normals (Sykes et al., 1972; Cohen & Douglas, 1972; Firestone & Douglas, 1975). There are no differences observed on simple RT or self-paced choice RT tasks (Douglas & Peters, 1979). One study (Sykes et al., 1973) found no differences between hyperactives and normals on choice or serial RT tasks. The serial task although continuous, was self-paced, with low sustained attention demands. In contrast, the choice task was divided into discrete trials. Mean number correct was equivalent for the two groups, and both groups demonstrated slower and more variable RTs as the complexity of the task increased (Sykes, et al., 1973). While there were no differences in latency measures (e.g. RTs) the hyperactives made more errors than normals. This suggests that hyperactives can perform well on RT tasks provided they are presented as discrete trials with brief trial durations. As the demands of experimenter-paced tasks increase, the performance of hyperactives deteriorates (Sykes, et al., 1973). Also, some RT tasks require sustained attention or preparation to warning signals which penalizes hyperactives (Douglas &

Peters, 1979).

It appears that what differentiates the RT performance of hyperactives from normals is their erratic, variable quality (Douglas, 1983; Stamm & Kreder, 1978). Although studies have demonstrated that they are capable of good RT performance (Sykes, et al., 1973), they frequently do not perform well (Stamm & Kreder, 1978). Douglas (1983) attributes this to the inability of the hyperactive child to react efficiently and consistently to the target stimuli and to withhold inappropriate responses. The fact that hyperactives are capable of making appropriate responses but often fail to do so argues against behavioral arousal difficulties as an explanation for the poor performance of hyperactive children on some RT tasks. Were they uniformly impaired by basic arousal difficulties, they would not be expected to perform well in any RT situation.

Psychophysiological Studies of Arousal

Heart Rate. Early studies which viewed hyperactivity as a problem of overarousal were based on behavioral observation of overactivity and distractibility. The ameliorative effect of stimulant medication on overaroused children was seen as paradoxical. Results have generally not supported the overarousal theory. Several studies have failed to demonstrate elevated resting heart rates in hyperactive children relative to controls (Barkley &

Jackson, 1977; Zahn et al., 1975; Sroufe, et al. 1973). One study demonstrated slightly faster heart rate (Ballard, Boileau, Sleator, Massey & Sprague, 1976), however these results have not been found consistently (Hastings & Barkley, 1978).

Heart rate decelerations have been associated with increased alertness to warning signals in vigilance tasks and during orienting responses (Rohrbaugh, 1984). There is some evidence of smaller heart rate changes in response to stimulation in hyperactive children relative to controls. Sroufe and colleagues (Sroufe et al., 1973) found that hyperactives demonstrated smaller cardiac decelerations in response to warning signals during a reaction time task than normals. This has not been extensively studied however (Hastings & Barkley, 1978).

Electrodermal Measures. Resting measurements of electrodermal activity have been similarly inconclusive. Tonic or basal skin conductance levels have not been shown consistently to differ from normal controls (Conners, 1975; Firestone & Douglas, 1975; Cohen & Douglas, 1972; Zahn et al., 1975). Satterfield and colleagues (Satterfield & Dawson, 1971; Satterfield, Cantwell, Saul & Yussin, 1973) found that basal skin conductance as well as phasic skin conductance (e.g. skin response to stimuli rather than resting levels) in hyperactives was lower than normals, leading them to propose that they are underaroused rather than overaroused. Proponents of the underarousal hypothesis (presumably due to reduced central nervous system (CNS) excitability) often view hyperactive behavior as a corrective attempt to increase internal and external stimulation (Zentall, 1975). The underarousal hypothesis is intuitively appealing in that it resolves the paradoxical effect of stimulant medication. If the child is underaroused rather than overaroused, stimulants simply correct the original defect. The frequent observation that hyperactivity is often reduced in situations where the child is inherently aroused provided further appeal for this idea. The underarousal hypothesis was often interpreted to reflect a maturational lag in hyperactive children, as their behavior and electrophysiological profiles were suggestive of younger, normal children. There has been little direct support for the underarousal hypothesis, and it is no longer widely accepted (Hastings & Barkley, 1978). There has been more support for an electrophysiological responsivity hypothesis rather than one of underarousal or maturational lag.

Numerous studies have found phasic skin conductance or galvanic skin response (GSR) in hyperactive subjects to be sluggish relative to normals, suggesting that rather than basal differences in electrodermal level there is a general under-responsiveness of hyperactive children responses to stimuli (Hastings & Barkley, 1978; Rosenthal &

Allen, 1978; Cohen & Douglas, 1972). Hyperactives have been shown on detection tasks to have fewer and smaller skin conductance responses to signal tones (Cohen & Douglas, 1972; Zahn et al., 1975), nonsignal tones (Satterfield & Dawson, 1971; Zahn et al., 1975) and to warning signals in reaction time tasks (Firestone & Douglas, 1975). Firestone and Douglas (1975) concluded that the arousal levels of hyperactive children are neither less than nor greater than normal children, but are insufficiently modulated to meet the specific demands of the tasks at hand.

EEG. Electroencephalographic (EEG) studies in hyperactive children have generally not supported either of the arousal deficit hypotheses. Minor EEG differences have consistently been found in hyperactive children, particularly higher EEG amplitude, broader range of amplitude and increased EEG slow waves (Satterfield et al., 1972). Fifteen to 40 percent of hyperactive children show abnormal EEGs, however 10 to 12 percent of normal children also have minor EEG differences (Hastings & Barkely, 1978). Thus, presence of abnormal EEG is not pathognomic of ADHD, and provides no support for basic differences in arousal. Large amplitude slow wave EEG patterns are highly correlated with states of sleep, drowsiness and coma (Vanderwoolf & Robinson, 1981), thus the presence of that activity in hyperactives was initially taken to support underarousal (Satterfield et al., 1972). However, other lines of available data do not supports this theory, as discussed above.

Cortical Evoked Response. The strongest evidence for arousal differences between hyperactives and nonhyperactives comes from the measurement of cortical evoked potentials (EP). EPs are averaged EEG parameters which are time-locked to stimuli. They measure responsiveness to stimulation rather than basal arousal. Positive and negative wave peaks are measured in response to presented stimuli. The size and duration of these waveforms have been correlated with orientation, arousal and attention (Hastings & Barkley, 1978; Harter & Aine, 1984). EP studies with hyperactive children suggest that there are baseline differences relative to normals as well as in response to stimulant medication (Hastings & Barkley, 1978; Rosenthal & Allen, 1978). These differences include increased variability in auditory and visual EPs (Satterfield et al., 1973; Satterfield et al., 1972; Buchsbaum & Wender, 1973). Two studies (Buchsbaum & Wender, 1973; Satterfield & Braley, 1977) demonstrated age effects in EP variability and amplitude, which was taken as further evidence of maturational lag. More recent work has failed to support this (Callaway, Halliday & Naylor, 1983). Loiselle and colleagues (1980) studied EEG and EPs during vigilance, selective attention and discrimination tasks, and demonstrated that hyperactives showed decreased EP enhancement to warning signals in vigilance paradigms relative to normals. Some see this as a cortical measure of a primary attentional deficit rather than maturational lag or underarousal (Loiselle, Stamm, Matinsky & Whipple, 1980).

Stimulants. Stimulant drugs have been shown to reduce the EP variability in hyperactives (Buchsbaum & Wender, 1973; Satterfield et al., 1973; Loiselle et al., 1980; Halliday et al., 1976) and to augment skin conductance responses (Stamm & Kreder, 1979; Sroufe et al., 1973). This may suggest that hyperactive children are somewhat underaroused cortically relative to normals, however this is only seen clearly in paradigms which measure responsiveness specifically (e.g., GSR and EP) rather than basal arousal level. Furthermore, these differences are seen in situations where the hyperactive child must remain alert to particular stimuli (often for prolonged periods) and respond differentially to certain stimuli (e.g., withhold inappropriate responses). This is consistent with Douglas' contention that primary deficits are seen in the maintenance and organization of attention and effort, and in the modulation of arousal level commensurate with situational demands (Douglas, 1983).

In summary, the available evidence does not support either extreme of the arousal hypothesis. Deficient autonomic reactivity rather than deficient basal arousal appears to be present. This is indicated by smaller and slower rates of change from baseline, decreased responsivity to warning stimuli and decreased evidence of autonomic enhancement under active attention in vigilance paradigms.

However, all of the available psychophysiological studies must be interpreted with caution. It is not possible to compare directly studies with methodologies and subject groups as varied as these. Some EP studies selected subjects with normal EEGs (Hall, Griffin, Moyer, Hopkins & Rappoport, 1976; Callaway, et al., 1983) while others did not (Loiselle, et al., 1980; Buchsbaum & Wender, 1973; Satterfield, et al., 1973; Hastings & Barkley, 1978). Many of the earlier studies included children with diagnoses of minimal brain dysfunction, who might not be diagnosed as hyperactive by current criteria. Moreover, these studies differ in the tasks used, the stimulus modality employed, the nature of the testing environment and the apparatus. Event related studies generally have tried to control for attentional state (Loiselle, et al., 1980) however earlier studies of basal and phasic differences where no orienting or attentional task was employed made no such attempts (Buchsbaum & Wender, 1973; Satterfield, et al., 1972). Consistent efforts to control for such variables as eye and head movements, which directly affect EP recordings (Stamm & Kreder, 1978; Loiselle, et al, 1980) have not been reported. Finally, there is no study published which matched subjects for baseline arousal level or attentional state, which would be necessary in order to assert definitively that hyperactive children are less arousable than other, nonhyperactive children.

Impulsivity, Inhibition and ADHD

Difficulty in inhibitory control, or the ability to withhold responses, is well established in hyperactives. Impulsivity has been measured on a wide array of tasks (Douglas, 1983), including vigilance and continuous performance tasks (CPT) (Sykes, et al., 1973; Sykes et al., 1971; Dykman et al., 1971; Zahn, et al., 1975; Halperin, Wolf, Pascualvaca, et al., 1988), the Matching Familiar Figures Test (MFFT) (Messer, 1976; Campbell, et al., 1971; Cohen, Weiss & Minde, 1972), maze tracing tasks (Parry, 1973) and various RT tasks (Firestone & Douglas, 1975; Zahn, et al., 1975). Impulsive responses fall into the categories of anticipatory errors (e.g. responding to cue signals rather than target signals in vigilance paradigms, responding during the preparatory interval in cued RT tasks), responding to nontarget stimuli other than cue signals, redundant responses and dyscontrolled responses. Difficulties with impulsivity have been proposed as a confounding factor in many studies of other cognitive processes (Douglas, 1983; Douglas & Peters, 1979).

CPT Studies. The "A-X" version of the CPT requires that a button be pressed to the target "X" only when preceded by the cue stimulus "A" ((Rosvold, Mirsky, Sarason et al., 1956). Sykes and colleagues used this task to demonstrate that hyperactive subjects detect fewer targets (hits), make increased errors of omission (misses) and errors of commission (false alarms) (Sykes, et al., 1971; Sykes et al., 1973). While CPTs are considered vigilance tasks, error analysis provides information about impulsive responding as well (Douglas, 1983; Halperin, et al., 1988). The presence of numerous false alarms is generally taken to reflect decreased inhibitory control and impulsivity (O'Dougherty, Nuechterlein & Drew, 1984; Sykes, et al., 1971).

Halperin and colleagues have recently shown that the A-X task (which is a frequently employed CPT paradigm in the hyperactivity literature) generates four different classes of commission errors, only some of which reflect impulsivity (Halperin, et al., 1988). These error types are associated with different RTs, which suggests that commission errors do not comprise a unitary psychological process such as "impulsivity". Few CPT studies have conducted error subtype analysis. One study (Sykes, et al., 1973) reported three broad error categories, including anticipatory responses, slow responses and random responses, and demonstrated that hyperactives make more anticipatory and random responses than normal children (Sykes, et al., 1973). Reports of impulsive responding in CPT studies which do not break down error types should be interpreted with caution. Moreover, CPT studies, while providing information about impulsive responding, are designed to place a high demand on the subject for sustained attention. Therefore, the confound of impulsivity with sustained attention on task performance is considerable (Sykes, et al., 1973; Douglas & Peters, 1979). The interaction between increased commission errors and sustained attention demands will be discussed further below.

MFFT Studies. Another commonly used test of impulsivity is the MFFT, which requires the child to match a sample stimulus to six visually similar choices, and select the identical figure. The cognitive demands of the task include concentration, visual search and analysis, and withholding inappropriate responses based upon surface similarities. The task yields both latency and error scores, and is thought to measure a reflectivity/impulsivity dimension in children (Kagan, 1964) Hyperactives have consistently been shown to perform poorly on this task, despite intact visual search and analysis capabilities (Douglas, 1983; Campbell, et al., 1971; Cohen, et al., 1972). They tend to respond with shorter latencies and increased errors (Messer, 1976; Campbell, et al., 1971; Cohen, et al., 1972), which is interpreted as impulsive responding. Douglas (1983) has raised questions as to the impulsivity interpretation of the latency measure based upon inconsistent findings, possible examiner influence on the child's performance and "inefficient looking" on the part of the hyperactive child.

Stimulants have been shown to slow down response latencies in hyperactives on the MFFT (Rapoport, Quinn, Bradbard, et al., 1974; Campbell, et al., 1971; Weingartner, Rapoport, Buchsbaum, et al., 1980). This effect is also seen on CPTs, although it is unclear if the medication works to decrease impulsivity or increase sustained attention (Sykes, et al., 1973; Cohen, et al, 1971; Rapoport, Buchsbaum, Zahn, et al., 1978). This result has also been reported in normal children (Rapoport, et al., 1978; Weingartner, et al., 1980).

Campbell and colleagues conclude that when faced with several response alternatives, such as on the MFFT, the hyperactive child will respond impulsively, without thoroughly examining the situation. Hyperactives also frequently fail to monitor their own behaviors, or correct errors (Campbell, et al., 1971). Overall, the hyperactive child employs less efficient problem solving strategies, which affects their school performance (Campbell, et al., 1971; Tant & Douglas, 1982). This is consistent with the assertion that the primary problems of impulsivity and inhibitory control (along with attention and effort) contribute to the behavioral sequelae which define hyperactivity (Douglas, 1983).

Attention and ADHD

Attention is not a unitary phenomenon, but is comprised of stages and subprocesses, including selection of information by focusing on salient features of the stimulus environment (selective attention) (Broadbent, 1971; Hirst, 1986; Shiffrin & Schneider, 1977), allocation of attentional resources (Kahneman, 1973; Sergeant & Scholten, 1985), maintenance of attention (sustained attention) (Parasuraman, 1984), and attentional shift (Mirsky, 1989; Davies, Jones & Taylor, 1984).

Not all authors agree that there is a particular preordained sequence in which attentional processing is carried out, however the notion that attention is comprised of various elements is well accepted (Mirsky, 1989). Some have argued that these processes are related to pools of processing energy which may be under some degree of subjective control (Schneider & Schiffrin, 1977; Sanders, 1983). Similarly, it has been argued that attentional states are skill-related, and therefore amenable to training (Hirst, 1986) or motivational states (Hasher &

Zacks, 1979). These aspects of attention are often referred to as "controlled" and acquired processes (Schneider & Schiffrin, 1977; Kahneman, 1973). On the other hand, certain aspects of attention are presumed to be "automatic" and innate, and unaffected by learning, practice, motivation or stress (Hasher & Zacks, 1979; Ackerman, Anholt, Holcomb & Dykman, 1986; Schiffrin & Schneider, 1977). The following discussion will review some models of attention which have been implicated in the cognitive problems of hyperactives.

Selective Attention

Definition. Selective attention refers to mechanisms which permit the organism to select one stimulus out of the stimulus environment in order to process it more thoroughly (Hirst, 1986). In some contexts, selective attention is analogous to focussed attention, which is the ability to direct processing selectively towards relevant stimuli while ignoring irrelevant stimuli (that is, resist distraction) (Mirsky, 1989).

Models of Selective Attention. The earliest models of selective attention were those of Broadbent (1958), who characterized attention as a limited capacity communications channel, with multiple input channels and a single output channel. Broadbent theorized that subjects could not process all the information that impinged upon them. To avoid perceptual overload, he posited a filter mechanism through which salient stimulus characteristics are used to select certain stimuli for deeper processing (Broadbent, 1958; Hirst, 1986). The point where the multiple channels converge is referred to as the "bottle-neck" (Hirst, 1986; Wickens, 1984).

Early filter theories arose from studies in which it was found that experimental subjects had limited ability to process information presented simultaneously. Studies were designed to induce stimulus overload in order to examine the ways in which processing suffers (Kahneman & Treisman, 1984). The best known of these paradigms is the shadowing or "cocktail party effect" (Cherry, 1953; Treisman, 1960). This effect suggests that stimuli presented to a subject already engaged in a primary processing task result in processing delays or perceptual degradation of the secondary material (Cherry, 1953; Broadbent, 1958; Moray, 1959; Posner, 1982; Hirst, 1986). Perceptual studies also showed that subjects often select between relevant and irrelevant information on the basis of simple stimulus characteristics (Kahneman & Treisman, 1984; Hirst, 1986).

Broadbent's model is essentially a parallel-to-serial processing chain. Processing of simultaneous inputs is parallel until the bottle-neck. Thereafter, only the flow of selected information is permitted, and the system functions as a serial processor (e.g., only one bit of information at a time) (Wickens, 1984). Broadbent believed that selection occurs early in the information processing chain (Broadbent, 1958), commensurate with the belief that selection of competing information was only on the basis of simple sensory information.

This tenet was challenged by subsequent theories which asserted that selection occurred later in the information processing chain (Moray, 1959; Treisman, 1969; Deutsch & Deutsch, 1963). Studies demonstrated that subjects could respond to their names on unattended auditory channels (Moray, 1959; Kahneman & Treisman, 1984) and process semantic material on unattended channels as well (Treisman, 1969; Deutsch & Deutsch, 1969). This led to the demise of early-bottle-neck theories which predicted that only surface detail could be handled in parallel (Hirst, 1986; Wickens, 1984). Later models did away with the notion of bottle-necks completely based upon data suggesting that deep, unconscious parallel processing is possible (Posner, 1082; Norman & Bobrow, 1975).

In contrast, newer "divided attention" theories suggest that the _entire_ processing system works to limit amounts of information which would overwhelm it (Hirst, 1986; Norman & Bobrow, 1975). Divided attention is chiefly concerned with the number of tasks which can be handled simultaneously, and the degree of interference one task imposes on a second one (Hirst, 1986). It has been shown that the more dissimilar the competing tasks are, the less interference one produces on the other (Treisman & Davies, 1973). Rather than structural limits on the number of tasks subjects can engage in or the level of processing they can achieve unconsciously, newer theories view attention as a more flexible "modular system' (Kahneman & Treisman, 1984).

Performance on divided attention task in the newer formulations depends upon subject skill and motivation, experience with the task, and relation between tasks (Hirst, 1986; Kahneman, 1973). Kahneman (1973) has introduced the concept of "effort", while others have discussed "resources" available for dual task performance (Norman & Bobrow, 1975). Current models of selective attention focus on the development of the abilities to time-share between multiple tasks, to combine multiple tasks into single, well trained skills, to develop higher order abilities through practice and to develop task "automaticity" so that fewer attentional resources are required for adequate performance (Schneider & Schiffrin, 1977;Posner, 1982; Hirst, 1986).

In summary, the original filter model failed to explain later data which suggested that people have the ability to handle multiple inputs at a deep level of processing (Hirst, 1986). The model was further weakened by the realization that selection between relevant and irrelevant stimuli can be based upon semantic features, which can only have resulted from deep processing (Hirst, 1986; Schneider, Dumais & Shiffrin, 1984).

Formulations which are more interested in process (e.g. the ways in which subjects develop attentional abilities) than structure (e.g. where the bottle neck is located) have replaced most filter theories in the explanation of selective attention and divided attention (Davies, Jones & Taylor, 1984; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; van der Meere & Sergeant, 1988a). Factor analytic studies using various attentional tasks have shown that selective attention should not be considered a unitary phenomenon. It appears that it may be broken down into selectivity, resistance to distraction and shifting components (Davies, et al., 1984).

Measurement of Selective Attention. Selective attention is measured in many ways. Selective and dichotic listening tasks, where subjects are presented competing auditory messages and asked to detect signals from nonsignals or to shadow one message while ignoring another have long been popular. Central versus incidental learning tasks, which cue subjects to recall certain central material in the presence of irrelevant, distracting information and subsequently test recall for the irrelevant material as well, have also been used (Davies, et al., 1984; Peters, 1977 in Douglas & Peters, 1979). Others have used speeded classification tasks, which require subjects to rapidly sort material into relevant and irrelevant piles or groups (Rosenthal & Allen, 1980). Finally, visual search tasks and Stroop type tasks have been used. The former may test target detection in the presence of distraction. The latter produces the classic "color word" interference by asking subjects to inhibit a well learned response (reading a color name) to produce a competing response (naming the competing color ink the word is printed in) (Stroop, 1935; Davies, et al., 1984).

Selection may also be inferred from evidence of time-sharing on attentional tasks (Davies, et al, 1984). The attentional demands of selection and focus should appear as slower processing time in the presence of distractors. The presumption that attention and cognitive work slows performance underlies the measurement of RTs in distraction conditions. All of the above tasks have been used to look for selective attention deficits in hyperactives, although no distinctions between possible selective attentional subprocesses have been made.

Selective Attention, Distraction, & ADHD. Many of the studies reviewed below claimed to study "distractibility", but it can be argued that they really examined selective attention (whether or not the authors refer to it as such). For most purposes, distraction may be thought of as the reverse of selective attention. Susceptibility to distracting stimuli may reflect failures of selective attention.

Hyperactive children are frequently thought to be inordinately distractible. They often appear either drawn to or unable to screen out irrelevant material in the stimulus environment (Douglas, 1983). Distractibility is seen as poor performance in the face of extraneous stimuli ("distraction effect"). Similarly, a distraction effect in hyperactives but not in controls would demonstrate high distractibility in hyperactives ("differential effect") (Douglas, 1983; van der Meere & Sergeant, 1988a). The distraction effect is typically measured as increased errors or slower response latencies in the face of distractors.

Numerous studies, however, have failed to show that hyperactives are particularly distractible. One study comparing hyperactive and control children on vigilance tasks with distracting and nondistracting conditions, was unable to show that intermittent white noise (the distraction condition) significantly reduced the performance of either group (Sykes, Douglas, Weiss & Minde, 1971). The authors raised the possibility that their task was not sufficiently difficult to elicit a distraction effect (Sykes, et al., 1971). Another study was able to demonstrate a distraction effect which was, however, not specific to the hyperactive group (Campbell, Douglas and Morgenstern, 1971). The presence of irrelevant pictures and color cues significantly increased color naming time for both hyperactives and normals (Campbell, et al., 1971). Two additional studies using a choice reaction time task with color cues as distractors (Sykes, Douglas & Morgenstern, 1973) and the Stroop color-word effect (Cohen, Weiss & Minde, 1972) did not demonstrate group differences in distraction.

There are a few studies which have shown differential effects of distraction. Using a computerized detection task, one recent study showed longer reaction times to stimuli presented with randomized distractors than to stimuli without distractors. Reaction time increased as a function of the number of distractors, with younger children being the most distractible. Moreover, children rated as ADHD were found to be more distractible than controls (Sharma, Wolf, Healey et al., 1988). That result has not been replicated yet. Radosh and Gittelman (1981) found that hyperactives were vulnerable to high and low appeal visual distractors while solving math problems.

Using a letter circling task, Zentall & Zentall (1976) demonstrated that hyperactive children performed better with distraction than without. They concluded that performance was facilitated by the attractive visual and auditory distractors. The authors interpreted this as stimulus seeking behavior on the part of the hyperactives to counter their chronic underarousal (Zentall & Zentall, 1976). However, as discussed above, the underarousal hypothesis has not held up, thus the meaning of this result is still debatable. Also, the protocol did not include a control group, therefore it is not possible to conclude that this finding is unique to hyperactives (Douglas & Peters, 1979). Zentall could not replicate this finding in a second study, and concluded that observed errors in hyperactives could result from impulsive responding and sustained attention difficulties (Zentall, Zentall & Barrack, 1978).

There is evidence to support the notion that studies of distraction are confounded by problems with sustained attention and impulsivity. An unpublished study using an incidental memory test and a selective listening task found that hyperactive subjects had difficulty with both the distraction and nondistraction conditions. The author attributed the high number of errors generated by the hyperactives to problems with sustained attention and inhibitory control, not distraction (Peters, 1977 in Douglas & Peters, 1979).

Using a speeded classification task with salient and irrelevant distractors, Rosenthal and Allen (1980) found that hyperactives made more errors when distractors were present. However, this was shown to be related to impulsivity rather than distractibility, as the hyperactive children traded response accuracy for speed (Rosenthal &

Allen, 1980; van der Meere & Sergeant, 1988a). A more recent study designed to test that hypothesis could not find distraction effects in hyperactive children, and also concluded that children in the hyperactive group have difficulties with sustained attention rather than distractibility (Aman & Turbott, 1986).

Incidental learning tests have been used to study distractibility, under the premise that if hyperactives are paying more attention to distractors, they would demonstrate better recall for distractors than for central memory items. Moreover, absolute incidental memory scores for hyperactives would be expected to be higher than for normals (Douglas, 1983; Douglas & Peters, 1979; Aman & Turbott, 1986). Studies have generally not supported this contention however. In their review, Douglas and Peters found no evidence that hyperactives are more likely to process and remember incidental material than normals (Douglas & Peters, 1979). Aman and Turbott similarly found no evidence of increased incidental memory in hyperactives (Aman & Turbott, 1986). The failure to demonstrate high levels of distractibility or increased incidental memory in hyperactives undermines the hypothesis that hyperactive children have deficits in selective attention (van der Meere & Sergeant, 1988a; Aman & Turbott, 1986).

Another recent study, using a complicated design based upon the selective attention model of Schiffrin and Schneider (1977), was also unable to find differential deficits in the presence of distraction (van der Meere & Sergeant, 1988a). Like the Campbell study above, subjects performed poorly in the distraction condition regardless of group. This study controlled for the effects of fatigue and vigilance decrement over time by permitting short breaks between blocks of trials. Additionally, the design analyzed impulsive responding in the form of speed-accuracy-tradeoffs. The hyperactive group was not found to be impulsive. The authors concluded, like Douglas and Peters (1979) and Douglas (1983), that the primary hyperactive deficit must lie in the area of sustained attention (van der Meere & Sergeant, 1988a).

Two studies in the psychiatric literature claimed to find differential selective attentional deficits (Loiselle, et al., 1980; Michael, Klorman, Salzman, et al., 1981). Both studies used selective listening tests, but is difficult to determine whether they in fact measured selective attention. Both studies called for continuous monitoring (Michael, et al., 1981) and detection of infrequent signals over lengthy periods of time (Loiselle, et al., 1980; Michael, et al., 1981). These are demands on sustained attentional mechanisms, which might confound measurement of selective attention. Thus, these studies cannot be considered to provide evidence per se for a selective attention deficit in hyperactive children. Others have made this point before. Douglas (1983) criticized the Loiselle study on the grounds that the authors "misunderstood the vigilance paradigm". Rosenthal and Allen (1978) assert that what is often described as distraction in fact refers to the interruption by novel stimuli of sustained attentional processes. It appears that hyperactive deficits in sustained attention confound distractibility in many studies. In sum, no evidence for defective filtering in hyperactives has therefore been demonstrated (Douglas, 1983; van der Meere & Sergeant, 1988a).

Sustained Attention

Definition. The terms "sustained attention" and "vigilance" are used somewhat interchangeably, both historically and in the present review. Sustained attention is a process closely related to arousal. Arousal provides a background state (often called "alertness") which permits a wide range of attentional functions, including maintaining attention over time (Parasuraman, 1984). Many authors have referred to this as the intensive as distinct from the selective aspect of attention (Kahneman, 1973; Parasuraman, 1984; Douglas & Peters, 1979). This term reflects the amount of attention given to the entire stimulus environment versus that applied selectively to more limited features. It is the general level of vigilance of the organism (Parasuraman, 1984). Mackworth defined vigilance as "a state of readiness to detect and respond to certain small changes occurring at random time intervals..." and also stressed the maintenance of this state over long periods (Mackworth, 1957).

Measurement of Sustained Attention. Measurement of sustained attention is essentially the measurement of detection and vigilance. Detection tasks are typically lengthy and repetitive, with frequent or infrequent target signals presented randomly. This is termed "continuous performance" (Parasuraman, 1984; Rosvold, et al., 1956) and can be measured by CPTs such as the one referred to earlier. Many different performance measures have been generated, including correct detections (hits), responses to nontargets (false alarms) and omission errors (misses). Sometimes variables derived from signal detection theory are used in the measurement of perceptual sensitivity (d') and response bias (ß), in order to evaluate detection efficiency on vigilance tasks (Davies, Jones & Taylor, 1984; Sperling, 1984).

Reaction time tasks have also been used to measure sustained attention (Posner & Boies, 1982). Posner established that the foreperiod preceding targets in cued RT tasks is in fact a vigilance condition (Posner, 1982; Posner & Boise, 1971). The subject must generate and maintain a state of alertness and prepare to respond to each trial (Posner, 1978; Douglas, 1983). The autonomic changes associated with the period between the warning signal and the appearance of the target are comparable to the changes found during traditional vigilance tasks (Posner & Boies, 1982; Douglas & Peters, 1979; Parasuraman, 1984).

Research on vigilance in adults has found that the quality of performance deteriorates over time. This is referred to as the "vigilance decrement", and is associated with measures of decreased tonic and phasic arousal (Parasuraman, 1984). The study of performance over time is a main feature of vigilance research (van der Meere & Sergeant, 1988b). Parameters such as probability of signal (event rate), signal quality, speed of presentation, probability of errors (related to the target:nontarget ratio) and the length of preparatory interval have all been shown to affect vigilance (Parasuraman, 1984; Davies, et al.; Rosvold, et al., 1956). Different vigilance tasks may thus recruit different psychological and attentional processes, and separate processes may be responsible for decrements in performance with different tasks (Parasuraman, 1984).

<u>CPT & Vigilance in ADHD</u>. There is much work documenting difficulties in sustained attention in hyperactive children (van der Meere & Sergeant, 1988b;

Dykman, Ackerman & Oglesby, 1979; Aman & Turbott, 1986; Weingartner, et al., 1980; Zelko, 1986; Goldberg & Konstantareas, 1981; Loiselle, et al., 1980; O'Dougherty, Nuechterlein & Drew, 1984; Sostek, Buchsbaum & Rapoport, 1980; Sykes, et al., 1973). In many of these studies, the CPT has been employed as a test of vigilance.

The basic cognitive requirements of the CPT include prolonged concentration upon simple visual or auditory signals and discrimination of the target signal from a background of perceptual noise. Additionally, the child needs to learn and encode the appropriate signal and response. Once encoded, she/he must provide the correct response to the designated target and withhold that response when faced with nontargets (Rosvold, et al., 1956; Buchsbaum & Sostek, 1980; Douglas, 1983; van der Meere & Sergeant, 1988b). The A-X version of the task (see above) has the additional feature of providing a cue (the letter A) to help the subject anticipate the target and mobilize attention (Schachar, et al., 1988). While this preparatory signal might help reduce missed targets, it also increases the probability of commission errors (Halperin, et al., 1988; Schachar, et al., 1988).

Among the earliest CPT studies of hyperactives were those of Sykes and colleagues (Sykes, et al., 1971; Sykes, et al., 1973), using variants of the Rosvold "X" and "A-X" CPTs to study sustained attention. Their first study found that overall, hyperactives made fewer hits and more false alarms than normals, and that the performance of hyperactives decreased over time (Sykes, et al., 1971). Reaction time was not measured. In addition, hyperactives were more active than normals during the CPT, especially during the second half, and stimulants improved CPT performance in hyperactives (Sykes, et al., 1971) . Unfortunately, the CPT used in that study was very short (3-5 minutes), and probably did not fully challenge sustained attentional processes.

The second study replicated and extended the original findings by comparing hyperactives to normals on two 15 minute CPTs (auditory and visual), a serial RT task and a choice RT task. They found that hyperactives had poor sustained attention on the first two tasks, as reflected by decreased hits, increased errors and performance decrements over time. Both hyperactive and normal subjects deteriorated with time on the CPT, however the hyperactive performance declined significantly more than normals (Sykes, et al., 1973). There were no group differences on the choice RT task, which only demands attention for brief periods. The authors also categorized errors, and found that hyperactives make more anticipatory and random errors than normals. They interpreted this as diminished inhibitory control superimposed upon sustained attentional difficulties.

Other studies with CPTs have supported the above findings. Using many variants of the CPT, more recent work has consistently found that compared to nonhyperactive controls, hyperactives identify fewer targets, respond more frequently to nontargets, have slower and more variable RTs, are more restless and commit more impulsive responses with longer task time (Michael, Klorman, Salzman, et al., 1981; Weingartner, et al., 1980; Klee & Garfinkel, 1983; Nuechterlein, 1983; O'Dougherty, et al., 1984; Zelko, 1988; Halperin, et al., 1988).

Signal Detection, CPT, & ADHD. Some recent studies have introduced signal detection analysis (Swets & Kristofferson, 1970) as a means of separating two presumed components of vigilance in hyperactives (Sostek, Buchsbaum & Rapoport, 1980; Nuechterlein, 1983; O'Dougherty, et al., 1984; Zelko, 1988). The analysis uses two measures; perceptual sensitivity (d') and response bias (ß).

Signal detection theory presumes that stimuli lie within two normal distributions; target signal alone and signal plus background perceptual noise. These distributions overlap to some extent, and it is here that the subject has difficulty discriminating signal from noise. Perceptual sensitivity (d') represents the subjects' ability to make this discrimination. Response bias (ß) represents the subjects' willingness to report a detection. (Swets and Kristofferson, 1970; Sperling, 1984).

Low perceptual sensitivity indicates difficulty discriminating among signal types, and low response bias reflects a tendency to respond impulsively in the face of ambiguous signals (O'Dougherty, et al., 1984; Sperling, 1984; Hirst, 1986). A subject adopting a low, or risky response bias might have a high hit rate but also commit many false alarms. On the other hand, a high response bias would result in a low false alarm rate but also a low hit rate (conversely, a high miss rate) (Sperling, 1984; Parasuraman, 1984). Moreover, decrements in d' and β over time are believed to index the vigilance decrement (Parasuraman, 1984). That is, a subject's ability to discriminate targets may deteriorate as the task duration increases or their response bias and motivation may change over time (Parasuraman 1984; van der Meere & Sergeant, 1988b). It seemed appropriate to apply these analyses towards studying the vigilance performance of hyperactives.

There is considerable evidence that hyperactives have diminished perceptual sensitivity relative to controls (O'Dougherty, et al., 1984; Zelko, 1988; Sostek, et al, 1980). Not all studies have found this to be the case however. Nuechterlein (1983) could not demonstrate differences in d' when comparing hyperactives to children at risk for schizophrenia and normal children, but did find decreased β in hyperactives. He concluded that hyperactives have an impulsive response style (Nuechterlein, 1983). Sostek and coworkers did not find decreased response biases (Sostek, et al., 1980), while others have shown both lowered perceptual sensitivity and response bias in hyperactives relative to controls (O'Dougherty, et al., 1984; Zelko, 1988).

CPT Changes Over Time & ADHD. CPT performance changes over time have not been well researched. Sykes and colleagues (Sykes, et al., 1971; Sykes et al., 1973) showed that the CPT performance of hyperactives declined markedly from the first to the second half of the task, whereas normal children improved with time (Sykes, et al., 1973). The authors concluded that hyperactives suffered a deficit in sustained attention.

Other groups have been unable to replicate this finding with the CPT. Several studies found that vigilance deterioration over time was not specific to hyperactives (Michael, et al., 1981; Schachar, et al., 1988; van der Meere & Sergeant, 1988b; Nuechterlein, 1983; O'Dougherty, et al., 1984). Some studies have not measured RT (Sykes, et al., 19771; Sykes, et al., 1973; Michael, et al., 1981), which is a parameter which might be expected to change over time. Clearly this area remains to be examined more systematically.

<u>Criticisms of CPT Methodology</u>. There are some clear reasons for discrepancies in the literature regarding CPT performance characteristics and deficits in hyperactives. Variations in tasks, subject and sample variables and differences in measurement are obvious contributors to the inconsistencies observed. Some CPTs were very short and probably did not effectively test sustained attention (O'Dougherty, et al., 1984; Zelko, 1988). That might explain the lack of time-associated decrements in that study. On the other hand, while another study's tasks appear to be of adequate length, the testing procedure specifically refocussed children whose attention was wandering by reminding them to look at the screen (Nuechterlein, 1983). This may have confounded measurement of sustained attention.

Similarly, task instructions vary considerably between studies. Some instructions are specifically for speed (Loiselle, et al., 1980; Weingartner, et al., 1980) while others stress accuracy (Michael, et al., 1981) or both (Halperin, et al., 1988; Schachar, et al., 1988). Some CPTs vary interstimulus interval and presentation rate depending upon performance accuracy, speeding up the rate when correct detections are made and slowing it when errors are made (Garfinkel & Klee, 1981; Weingartner, et al., 1980; Sostek & Buchsbaum, 1980; Sostek, et al., 1980). Target stimuli vary from study to study. Sometimes, the child must discriminate both color and number (Klee & Garfinkel, 1983) while others utilize single numbers (Nuechterlein, 1984; O'Dougerty, et al., 1984), pairs of numbers (Weingartner, et al., 1980) or pairs of letters (Sykes, et al., 1971; Sykes, et al., 1973; Michael, et al., 1981; Zelko, 1988; Halperin, et al., 1988). Still other tasks use computerized playing cards (Rutschmann, Cornblatt & Erlenmeyer-Kimling, 1986; Nuechterlein, 1984; O'Dougherty, et al., 1984), or auditory tone pips (Loiselle, et al., 1980) as stimuli. Target presentation rates vary from 10 percent (Michael, et al., 1980; Halperin, et al., 1988; Weingartner, et al., 1980; Klee & Garfinkel, 1983) to as high as 30 percent (O'Dougherty, et al., 1984). All of these variations have been shown to affect vigilance performance (Davies, et al., 1984).

Other Vigilance Tasks & ADHD. With these difficulties in mind, there have been attempts to assess sustained attention with methods other than the CPT. Research using the Delayed Reaction Time Task (DRTT) have also shown decreased and more variable RTs in hyperactives, and more erroneous responses (Firestone & Douglas, 1975; Cohen & Douglas, 1972). The latter study also showed a steeper decrement over time in hyperactives relative to normals (Cohen & Douglas, 1972).

Draeger and colleagues (Draeger, Prior & Sanson, 1986) specifically challenged the notion that hyperactives have difficulties in attention. Rather, they asserted, the problems lie in self-control, motivation and compliance (Draeger, et al., 1986). They measured signal detection and RT with auditory and visual tasks, and found no differences in d' or ß in hyperactive children relative to controls. However, they did find that hyperactive performance deteriorated in experimenter-absent conditions (Draeger, et al., 1986). They concluded that hyperactive children have difficulties in self-control in the absence of external structure rather than a sustained attentional deficit (Draeger, et al., 1986). The authors describe their visual task as a "selective sustained attention task" (Draeger, et al., 1986). It is not clear that they understood the selective and sustained attention paradigms. This is reminiscent of Douglas' (1983) criticism of the "selective attention" study of Loiselle (1980). In fact, Loiselle's task assessed sustained attention, and reported decreased mean detections, increased false alarms, and slow, variable RTs. Performance changes over time were not examined. It was the conclusion of a "selective attention deficit" which was unwarranted.

Unfortunately, many other workers claiming to measure sustained attention have suffered from the lack of validity of their instruments. One study (Aman & Turbott, 1986) utilized a letter cancellation task to assess sustained attention, however there is no mention of task duration.

This makes it difficult to evaluate its adequacy as a measure of sustained attention as opposed to visual search. Similarly, another study cited correlations between CPT error scores and other presumed measures of attention to make a point for decreased vigilance in hyperactives (Klee & Garfinkel, 1983). However, the use of the MFFT, WISC-R coding and arithmetic subtests and teacher ratings of behavior problems cannot be taken as tests of sustained attention as defined above.

Dykman and colleagues reported sustained effort differences and deterioration over time in a hyperactive group using a visual search task (Dykman, Ackerman & Oglesby, 1979). The hyperactive children in that study demonstrated "decreased tolerance for a problem" as evidenced by negative correlations between speed and accuracy during the latter part of the test (Dykman, et al., 1979). Controls demonstrated improvement in performance with time, and speed and accuracy were uncorrelated. Thus it appears that hyperactives may have traded speed for accuracy. This task was self-paced, however, which makes comparisons with experimenter-paced CPTs difficult. In a review of that study, van der Meere & Sergeant conclude that a speed-accuracy tradeoff evidences response bias, and suggest that Dykman's sample may have adopted a high risk, low bias strategy (van der Meere & Sergeant, 1988b). This would suggest that they were impulsive in responding, which is consistent with work reviewed previously.

<u>Summary</u>. Evidence generally supports a vigilance deficit in hyperactive children relative to normals, as evidenced by decreased hits, increased false alarms, slower and more variable RTs (Sykes, et al., 1971; Sykes et al., 1973; Michael, et al., 1981), diminished perceptual sensitivity (O'Dougherty, et al., 1984; Sostek, et al., 1980; Zelko, 1988), lowered response bias (Nuechterlein, 1984; Zelko, 1988), increased impulsive responding and possible decrements over time (Sykes, et al., 1971; Sykes, et al., 1973). This conclusion is strengthened by evidence that stimulant medication improves the performance of hyperactives on CPTs, mediated presumably by the ability of stimulants to enable subjects to resist cognitive fatigue and enhance attention (Weingartner, et al., 1980; Sykes, et al., 1973). Hyperactive deficits in sustained attention appear to be superimposed upon or to coexist with deficits in response inhibition and impulsivity. Thus CPT and vigilance studies appear to confirm Douglas' (1983) assertion that the deficits in hyperactivity involve sustained attention and effort, inhibition of impulsivity and arousal. Unfortunately, CPT research has not been well standardized, thus direct comparison of studies is not possible. Moreover, research into the cognitive demands of vigilance testing in children has been scarce until

recently. The CPT is a particularly useful and informative test, however a better understanding of how it measures attention and how those measures relate to other cognitive processes is necessary.

PILOT EXPERIMENTS

A host of different measures have been used to assess attention, often yielding inconsistent results. It may be that these instruments in fact evaluate different attentional subprocesses. Two pilot studies were performed to examine separation of attentional subcomponents, and the behavior of different clinical groups on different attentional factors.

Three commonly used methods of evaluating attentional abilities have been the attentional triad of the WISC-R (arithmetic, digit span and coding subtests) (Gardner, 1979; Kaufman, 1979), continuous performance tests (CPT) (Rosvold, Mirsky, Saranson, Bransome & Beck, 1956; Gardner, 1979) and various paper and pencil target cancellation tests (Gardner, 1979; Lezak, 1983). All have been used both clinically and in research to detect problems of attention.

Many investigators and clinicians continue to advocate the attentional triad as a method of evaluating ADHD, despite the cautions of other workers in the field (Kaufman, 1979; Schwartz, Healey, Halperin, et al., 1989). Some authors have used the CPT as a measure of sustained attention (Sykes, Douglas & Morgenstern, 1973) while others advocate the use of cancellation tasks (Gardner, 1979; Lezak, 1983; Aman & Turbott, 1986). There has been relatively little investigation of the relationships and overlap between these instruments. Indeed, it is often unclear which psychological processes are being assessed by each, let alone whether they measure similar or different processes.

Attentional assessment is particularly important in evaluating childhood behavior disorders, as many of these are thought, in part, to involve attentional deficits. The symptoms of ADHD discussed above are also common in other disorders. For example, inattention is frequently present in Conduct Disorder (Biederman, Munir & Knee, 1987), learning disabilities (Douglas & Peters, 1979; Douglas, 1983), and other severe psychopathologies (Biederman, Munir & Knee, 1987; Werry, Reeves & Elkind, 1987). Thus, there is much overlap between distinct diagnostic groups which share some common symptoms.

Pilot work was undertaken to explore relationships between purported measures of attention and other tests of verbal and spatial functioning in a mixed psychiatric sample (Wolf & Halperin, 1987; Wolf, Newcorn, O'Brien, et al., in preparation). A mixed sample was used because of the prevalence of attentional difficulties in many disorders of childhood. Thus, the interest was in the dimensional <u>and</u> categorical nature of attention rather than in the different diagnostic groups. The goal was to investigate the measures used in the assessment of attention.

This was done in two experiments. The aims of Pilot Experiment 1 were to determine whether various purported measures of attention assess similar or different functions, and whether these instruments gauge attention independent of other cognitive processes. Pilot Experiment 2 addressed diagnostic questions; do patients in different diagnostic groups which share attentional symptoms have similar or different attentional profiles.

Pilot Experiment 1

A diagnostically heterogeneous sample of 62 children from the child psychiatry service of a major metropolitan hospital was studied. Table 1 in Appendix A presents sample characterstics. The age range was 5.75 to 13.75 years, with a mean of 9.25 years. The majority of the patients were male (n=53), with 61% inpatients and 39% outpatients.

Most children were administered a battery of psychological tests as part of their diagnostic evaluation, including the Wechsler Intelligence Scale for Children-Revised (WISC-R, Wechsler, 1974). All of the children had IQs above 80, therefore no child of borderline intelligence was included in the sample. WISC-R subtest scores were collapsed into the 3 factors described by Kaufman (1979). The Verbal factor was derived from scores from the Information, Similarities, Vocabulary and Comprehension subtests. Freedom from Distractibility was based upon Arithmetic, Digit Span and Coding scores. Finally, the Perceptual Organization factor was comprised of scores from the Block Design and Object Assembly subtests.

Each child also performed two additional tests of attentional functioning; a continuous performance test (CPT) and a target cancellation test. The CPT was modelled after the A-X task described by Rosvold et al. (1956). CPT data obtained for each subject were hit percent (hits/total targets), number of false alarm or commission errors (CPT-FA), mean reaction time for hits (CPT-RT) and reaction time variability (intrasubject standard deviation for hit RTs (RTSD)).

The target cancellation test (Rudel, Denckla & Broman, 1978) was a paper and pencil task requiring the subject to scan 3 separate pages with rectangular arrays of letters, numbers or geometric shapes, respectively, and cross out designated targets as quickly as possible. This task yielded separate measures of accuracy (total errors for each form) and speed (total search time), which were collapsed across all three forms.

A Principle Components Factor Analysis with Varimax Rotation was conducted using the 3 WISC-R factor scores (i.e. Verbal, Freedom from Distractibility and Perceptual

Organization), normalized scores for four CPT measures (i.e. hit percent, CPT-FA, CPT-RT and RTSD) and two cancellation test measures (errors and search time).

<u>Results and Discussion of Pilot Experiment 1</u>

The Rotated Factor Matrix is presented in Appendix A, Table 2. The four factor solution suggests that several presumed tests of attention assess separable functions. Two of the factors (Factors 1 and 3) appeared to be related to aspects of attention or behavior to which the CPT is sensitive. Factor 1 contained loadings from two CPT measures of accuracy (percent hits and false alarms). It is thought to be related to behavioral control, as false alarms are generally believed to reflect deficits in response inhibition. Here, false alarms were negatively associated with percent hits (which reflect good performance). Factor 3 contained loadings from the other two CPT measures (reaction time and RT variability), and is thought to be related to speed and consistency of responding rather than control. This may in turn reflect sustained attention, or at least consistently maintained effort in responding.

The other two factors appeared to be related more to perceptual abilities. Factor 2 contained loadings only from cancellation errors, and might be construed as reflecting visual attention or visual search. However, since no other test shared variance with that measure, interpretation from a single factor loading is at best, speculative. The fourth factor is probably not an attentional factor at all. Its loading of cancellation speed and the WISC-R Perceptual Organization factor suggests rather a visual search/scan factor.

The results of this pilot work suggested that CPT and cancellation tests measure separable processes and thus cannot be used interchangeably as measures of "attention". Furthermore, both of these tasks were unrelated to verbal functioning, and the CPT appeared unrelated to perceptual organization. In addition, CPT measures may assess separable processes of performance; accuracy/behavioral control, and speed/consistency. Speed and accuracy measures were distinct on both the CPT and the cancellation task, suggesting that the dichotomy of control versus speed/consistency is a valid one. It appeared further that various measures of attention are neither directly comparable nor interchangeable as unitary measures of attentional functioning.

These results are reminiscent of another factor analysis (Sack & Rice, 1974), which subdivided selective attention into selectivity (or focussing ability), resistance to distraction (maintenance of focus) and shifting components. Thus, the application of factor analytic techniques to elucidate structural or process differences in attentional performance is a fruitful means of generating hypotheses about the manner in which these subprocesses may be organized.

In addition to exploring possible factors underlying experimental variables, it is also important to test these hypotheses more stringently. The factor analysis may be construed as an exploratory step which establishes construct validity by determining the number of underlying variables among larger sets of measures (Kerlinger, 1974). To the extent that the resulting factors are comprised of variables which share common factor variance, the procedure essentially separates independent factors which may have some psychological process in common. This factor or construct may then be treated as a variable in its own right, and be subjected to statistical procedures as any other dependent variable. This was the aim of the second pilot analysis.

Pilot Experiment 2

This experiment tested the hypothesis that children with Attention Deficit Disorder (ADD), Conduct Disorder (CD) and Mixed Attention/Conduct Disorder (ADD/CD) would differ on measures of behavioral control and speed/consistency generated from the factor analysis in Pilot Experiment 1. To the extent that those factors were derived from attentional and vigilance tasks, it was hypothesized that children with ADD would have trouble with both speed/consistency and behavioral control. As CD is not considered a primary disorder of attention, children with that diagnosis as a group were not expected to have particular difficulty with either speed/consistency or behavioral control. No specific predictions were made regarding the ADD/CD group, nor were hypotheses generated for the other two factors.

The charts of 51 children from Experiment 1 were reviewed by two child and adolescent psychiatrists blind to CPT data, and DSM-III diagnoses were determined. Children with DSM-III diagnoses of "pure" ADD (n=7), "pure" CD (n=10) and Mixed Attention Deficit/Conduct Disorder (n=24) were compared. Children were diagnosed as "pure" CD if both raters assigned a diagnosis of CD and neither diagnosed the child as ADD. A diagnosis of "pure" ADD was assigned if both rated the child as ADD and neither diagnosed him as CD, and a Mixed diagnosis resulted if both raters agreed on some combination of CD and AD. Children who were judged to have a disorder other than ADD or CD (n=10) were not included in these analyses. Descriptive statistics are found in Table 3, Appendix A. There were no significant differences between the groups for age or full scale IQ.

<u>Results and Discussion of Pilot Experiment 2</u>

Factor scores, which are weighted averages based upon factor loadings, were derived for each subject on the basis of the factor analysis in Experiment 1 with the factor score program of the SPSS statistical package. Thus four factor scores were derived for each subject. In order to analyze factor score differences between the three diagnostic groups, a one-way analysis of variance was performed. Where significant differences emerged, post-hoc comparisons were performed to compare the individual groups.

Factor scores were scaled such that high scores on Factor 1 (Behavioral Control) and Factor 4 (Perceptual organization) represent good performance, and low scores represent poor performance. Low scores on Factor 2 (Visual Attention) and Factor 3 (speed/consistency) represent good performance, and poor performance is indicated by high scores. Mean (SD) factor score values are presented in Appendix A, Table 4.

It was originally predicted that the ADD group would demonstrate difficulties with both behavioral control (Factor 1) and speed/consistency (Factor 3), while the CD group would not have difficulties with either. A trend ($F(2,38)=2.91$, $p<.06$) supported the prediction of diminished behavioral control in the hyperactive group. Children with the ADD diagnosis had the most problem with behavioral control, as evidenced by the lowest Factor 1 scores. The CD group demonstrated the best scores on this factor. The ADD/CD group had scores intermediate between the other groups. The difference between the three groups on speed/consistency (Factor 3) did not approach significance. There were nc significant differences between the groups on the other two factors.

Summary of Pilot Studies

A factor analytic study of scores from various commonly used attentional and cognitive tests was conducted on a sample of 62 children with mixed psychiatric diagnoses. Two factors related to CPT/vigilance performance emerged; a behavioral control factor and a speed/consistency or sustained attention factor. Two other factors were related to visual and perceptual organization. These factors were collapsed into dimensional factor score variables, which were tested for differences in three diagnostic groups. A trend supported the prediction that children with ADD would perform poorly on the behavioral control factor relative to children with CD or a Mixed ADD/CD diagnosis. No significant group differences emerged for sustained attention, contrary to predictions that the children with ADD would have difficulties here as well, relative to children with other diagnoses. The small sample size of the ADD group and their wide variability of scores may have contributed to the lack of significant results.

EXPERIMENT 1: Separation of Attentional Factors in Children

The purpose of Experiment 1 was to examine the separation of attentional factors in a non-referred sample of school-age children. The aims were twofold: 1) to replicate the findings of the pilot study in normal children, and 2) to examine those features of attentional (dys)function which might be related to teacher ratings of behavioral problems.

Whereas reports of attentional difficulties in ADHD are well documented, there has been less work on the nature of attention in normal children. Moreover, few of these studies have examined the possible separation of attentional problems. As has been discussed previously, there is evidence that various assessment methods yield inconsistent results. This may be due to measurement difficulties (e.g. the lack of direct comparability of different assessment protocols), subject differences (e.g. different diagnostic criteria, age groups or overlap between diagnostic groups), confounds between attention and other cognitive processes (such as impulsivity) or because previous studies have treated "attention" as a unitary phenomenon.

Studies which purport to measure attention deficits must first establish that the measures used in fact measure attention, and that they do so in a consistent manner.

Construct validity in ADHD research has typically been established by comparing children with ADHD with normal children, however there are other ways to approach this. The first experiment aimed to study the factor structure of attentional tests in a non-referred sample in order to establish whether attentional functioning in children is comprised of more than one element. Thus, the first broad aim was to discern some of the factor(s) underlying attention which are assessed by common instruments. It then becomes possible to examine how these factors may be affected differentially in behavior disorders. This was the second broad aim of this study.

The specific predictions of Experiment 1 were as follows:

1. A speed/consistency factor will emerge which represents sustained attention in children. This factor is comprised of measures of RT and RT variability on the CPT.
2. A behavioral control factor will emerge, which is comprised of measures of response accuracy (false alarms and hits) on the CPT.
3. Behavioral control and speed/consistency are not related to intelligence or other purported tests of attention such as target cancellation, Digit Span and MFFT.

4. The behavioral control factor will correlate with teacher ratings of behavior problems in the classroom.

5. The speed/consistency factor will not correlate with teacher ratings of disordered behavior.

Method

Subjects

The initial sample consisted of 85 first to sixth grade (6 to 13 year old) children from a parochial school in a major metropolitan area (Mean=9.00, SD=1.62). This age range was used because symptoms of ADHD are most notable during those years and because the measures used are standardized for this age group. There were 42 boys and 43 girls. Approximately 57% of the school participated in the study. The students who participated were not different from the remaining students with respect to their performance on standardized tests of reading [$t(124)=-0.76$, $p>.10$] or arithmetic [$t(124)=-0.78$, $p>.10$]. It was felt that the sample was representative of the school population.

Only children with parental consent participated in the study. Additionally, children who were known to be receiving psychiatric treatment for behavior problems were excluded from the sample. In order to ensure that no mentally deficient children were included, a minimum

Peabody Picture Vocabulary Test-Revised (PPVT) score of 70 was required for inclusion in the final sample. This reduced the sample to 72 children (36 boys and 36 girls), with a mean age of 9.1 years. The mean (SD) PPVT standard score for the sample was 91.3 (14.6).

Clinical Scales. Subjects were divided into two groups based upon the IOWA scoring (Loney & Milich, 1982) of the Revised Conners Teacher Questionnaire (CTQ) (Goyette, et al., 1978). The CTQ is a 28 item checklist which samples a wide range of problem behaviors in the classroom. Teachers are asked to rate each child for symptoms of inattention, hyperactivity, aggression and learning problems in the classroom. Examples of questions include "demands must be met immediately--easily frustrated", "restless and overactive", and "fails to finish things he starts--short attention span". Ratings are on a four point scale for each item, from "not at all" (0), "just a little" (1), "pretty much" (2) to "very much" (3). A higher score therefore indicates greater level of symptomatology.

There are several different scoring methods for the CTQ, which yield slightly different scores. The IOWA scoring utilizes only those questions from the CTQ which were shown to substantially correlate with two independent, empirically derived, dimensions of inattention/overactivity (IO) and aggression (A) (Loney &

Milich, 1982; Hinshaw, 1987). Only the IO subscale was used in the current study. The five items from the CTQ which comprise the IO subscale are: restless in the "squirmy" sense, makes inappropriate noises, distractibility or attention span a problem, excitable or impulsive, and fails to finish things.

A criterion score of 7 for hyperactivity (IO) is considered the acceptable clinical cutoff, and a score of 11 is often used as a more stringent research cutoff (Loney & Milich, 1982). The authors demonstrated that an IO cutoff score of 7 correctly identified 85 percent of children rated as hyperactive, with a false positive rate of 13%.

As the present study utilized an unselected school sample rather than a true patient sample, the decision was made to use the more lenient clinical cutoff of 7 rather than the more stringent research criteria of 11. It was felt that this would result in a larger behavior disordered sample within an otherwise normal population. The research criteria of the IO scale was, however, utilized in addition to the clinical score in some analyses. This was done to examine difficulties in behavioral control in both "clinical" and more severely disordered research samples in order to a) validate the use of the clinical scale for research and b) more closely examine the nature of behavioral control in a stringently selected sample.

The current study utilized the IOWA Conners to divide the sample into a hyperactive group and a nonhyperactive control group. Due to the intercorrelation between the subscales, no attempt was made to form "pure" hyperactive, inattentive and/or aggressive groups. Children were identified as "attention/behavior disordered" (which, for brevity sake are referred to as "hyperactive") or as nonhyperactive controls.

Children scoring greater than 7 on the IO scale were considered to have significant problems of hyperactivity. Children scoring below 7 were not considered to have significant attention/behavior problems. Children scoring 11 on the IO scale were considered to represent a more stringently defined subset of hyperactives. The A subscale was not used to divide the groups.

Hyperactives. The IOWA Conners clinical scale yielded a group of 21 children (17 boys and 4 girls) who were identified by teachers as presenting significant problems of attention and behavior. The control group consisted of 51 children who were not considered by their teachers to have significant problems of attention or behavior. Rating scale data was available for all subjects.

The two groups did not differ in age [$t(70)=1.55$, $p>.10$] or intelligence, as estimated by the PPVT [$t(70)=.49$, $p>.10$]. The means (SDs) of descriptive and dependent variables are presented in Table 1.

Table 1. Mean (SD) of Descriptive Variables Broken Down by Groups

	Controls (n=51)	Hyperactives (n=21)
Age	9.23 (1.69)	8.71 (1.36)
PPVT Standard Score	91.8 (14.63)	89.95 (14.7)

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"Research" hyperactives. The more stringent research criteria (IO greater than 11) yielded a hyperactive group of 12 children. The mean (SD) age of the sample was 8.79 (1.58) years and the mean (SD) PPVT standard score was 85.17 (11.33). This sample ("research hyperactives") was not significantly different from the normal control group in age [t(61)=.81, p>.10] or PPVT [t(61)=1.47, p>.10].

Procedure

A consent form was sent to the parents of all students in the school. Teachers completed the Revised Conners Teacher Questionnaire (CTQ) (Goyette, et al., 1978) for all students with parental consent. All subjects were administered a brief neuropsychological test battery which was designed to detect problems of inattention and impulsivity in children. The battery lasted approximately one hour, and was administered in one session. All tests were administered individually in the school by two examiners who were blind to group membership. Test order was designed to minimize the effects of fatigue, and was identical for all subjects. The following scales and tests were administered:

1. Revised Conners Teacher Questionnaire (CTQ)
2. Continuous Performance Test (CPT)
3. Target Detection Test (TDT)
4. Matching Familiar Figures Test (MFFT)
5. Digit Span subtest of the WISC-R
6. Peabody Picture Vocabulary Test- Form L (PPVT)

<u>Revised Conners Teacher Questionnaire</u> (CTQ) (Goyette & Conners, 1978). The Revised CTQ was discussed above. Although the IOWA scoring was used to divide the groups, the three original Conners factors (Conduct Problems, Hyperactivity and Inattention/Passivity), which were derived from factor analyses of the questionnaire were used as dependent measures in some correlational analyses. Scores for these dimensions may be calculated for each child by summing the ratings of the different questions which comprise the factor. Although they are often thought to be relatively independent (as none of the factors is made up of overlapping questions), several studies have reported substantial intercorrelation between all three factors (Shapiro & Garfinkel, 1986; Hinshaw, 1987).

The IOWA scoring system of the CTQ (Loney and Milich,

1982) yields the relatively more independent Inattention/Overactivity (IO) and Aggression (A) scales. The IOWA scoring was developed to attempt to correct for the fact that all three of the original Conners factors described above are strongly intercorrelated (Loney & Milich, 1982; Hinshaw, 1987). By selecting items which only correlated with empirically derived diagnostic classifications, the authors hoped to derive independent scales (Loney & Milich, 1982). Thus, this system purports to result in purer measures of disordered behavior than the original Conners factor scores.

The current study used the clinical cutoff score fo 7 on the IOWA to divide the groups, however in one analysis two different IOWA hyperactivity cutoffs were utilized. The Revised CTQ is found in Appendix B.

Continuous Performance Test (CPT). The CPT was modelled after the A-X task described by Rosvold et al. (1956). It was programmed to run on a Commodore-64 computer with a color monitor. Twelve single letters were randomly presented on the video monitor for a duration of 0.2 sec., with a 1.5 sec. interstimulus interval. The entire task lasted approximately 12 minutes. Each child was instructed to monitor the screen and to respond manually by pressing the space bar on the keyboard as quickly as possible whenever he/she saw an "A" followed by an "X". The computer was programmed such that targets appear randomly at a 10% frequency. A total of 400 stimuli were presented.

All children were trained by verbal instruction, followed by a trial test using a card that contained various letter combinations, and finally on a slowed version of the actual task. During the practice trials the examiner reinforced correct responses by saying "good" and pointed out errors. When it was ascertained that the child understood the task, the actual test began. After the test began, and the child made two correct responses, the examiner moved away until the task was completed.

CPT measures obtained for each subject were total hits, number of false alarm or commission errors (CPT-FA), mean reaction time for hits (CPT-RT) and reaction time variability (intrasubject standard deviation for hit RTs (RTSD)). In addition, signal detection measures of d' and β were calculated for each subject.

Target Detection Test (TDT). This target cancellation test modified the task used in the pilot study (Rudel, Denckla & Broman, 1978). That was a paper and pencil task which required the subject to scan 3 separate pages with rectangular arrays of letters, numbers or geometric shapes, respectively, and cross out designated targets as quickly as possible. It yielded separate measures of accuracy (total errors for each form) and speed (total search time).

Pilot analyses demonstrated that the accuracy and speed measures generated by that test are not necessarily related to attention. To the extent that cancellation speed was associated with perceptual organization and visual scan, it appeared that the task shares common skills with reading. This is supported by evidence that it discriminates dyslexic from nondyslexic children (Rudel, et al., 1978). Thus this task may confound with reading ability. It was modified to reduce the reading load and to eliminate the speed measure.

The present task presented stimuli in a random rather than row-by-column array on the page. The test booklet contained 6 pages of varying difficulty and stimulus type. The first two pages contained 75 stimuli with single letter (X) or number (5) targets, and the next two pages contained 150 stimuli with the same targets. There were 10 targets for each of the first two pages (13% target frequency) and 15 targets (10%) for the next two pages. The last two pages contained 150 trigram stimuli with letter (LIF) or number (592) targets, with a 10% target frequency. Nontarget stimuli were visually similar to target stimuli (e.g. "LIK" or "562"). Scores reflected the number of correct targets detected within a fixed time period.

Instructions to the child were to cross out the target stimuli as quickly as possible. All children used #2 pencils provided by the examiner. Each page contained the designated target as a reminder at the top, so as to reduce the memory load for the subject. Brief time limits were established for each group of stimuli (short form single targets, long form single targets, and trigrams) based upon pilot work. These limits ensure that few, if any, children can detect all targets, in order to control for ceiling effects. Targets detected for each form were summed across all 6 forms, to yield a single TDT accuracy score. The maximum TDT score possible is 80. This test and the norms from the pilot studies are presented in Appendix B.

Matching Familiar Figures Test (MFFT) (Kagan, 1964). The MFFT requires the child to match a sample visual stimulus to six similar choices, and select the identical figure. The cognitive demands of the task include concentration, visual search and analysis, and withholding inappropriate responses based upon surface similarities. The task yields both mean latency to first response and error measures, and is thought to measure a reflectivity/impulsivity dimension in children (Kagan, 1964). The difficulties of hyperactive children on this task were discussed above. It was included as an additional measure of impulsivity. Latency and error scores were collapsed into a single impulsivity score based upon Z-score transformations by age group (Salkind & Wright, 1977). For each subject, this Z-score was converted to an "SAT" score, with a fixed mean (SD) of 500 (100). The formula for the Z-score transformation appears in Appendix B.

The Digit Span Subtest of the WISC-R (Wechsler, 1974). The Digit Span test is a commonly used measure of attention. It requires the subject to repeat number strings of increasing length. In the first part, the child is required to repeat the strings exactly as heard. In the second part s/he is required to repeat the strings backwards. Rather than utilizing WISC-R scaled scores, a variable (Digits F+B) was created which was the sum of the number of digits correctly repeated forwards and the number of digits correctly repeated backwards.

The Peabody Picture Vocabulary Test-Form L (PPVT). (Dunn & Dunn, 1981). This task is commonly used as a measure of receptive vocabulary and language skills. It requires the child to chose a picture out of an array which best describes a word read by the examiner. The PPVT correlates highly with other tests of intelligence, and is well accepted as a brief measure of cognitive ability. Two measures from the PPVT-R were used; the raw score and the age standardized score (which has, like traditional IQ scores, a mean value of 100 and standard deviation of 15). PPVT-R standard scores of 70 or greater were required for participation in the study.

In addition to the above tests, standardized scores from the reading and arithmetic subtests of the Comprehensive Test of Basic Skills were obtained from school records. This test is a commonly utilized global test of academic achievement which was administered to all children in the school at the end of the academic year. Test scores were obtained for 64 of the children in the initial sample of 85. Scores for the remaining 21 children were not available. These scores were used to demonstrate that the sample was at least average in reading and arithmetic abilities, and that the two groups did not differ in these abilities.

Data Analyses

A Principal Components Factor Analysis with Varimax Rotation was conducted using 8 variables: 4 CPT variables (CPT Hits, CPT FA, Hit RT, Hit RTSD), total targets detected (TDT), PPVT raw score, MFFT Impulsivity/Reflectivity score (MFFT Impulsivity), and Digit Span Forward plus Backward (Digits F+B). Rather than using published standard scores for PPVT, MFFT and Digit Span, all raw scores were normalized for age on the current sample. This was done by Z-score transformations by age-group, as the variables are all highly age dependent. Eigenvalues of greater than 1.0 and factor loadings of greater than 0.45 were required for each significant factor.

Factor scores were derived from the above factor analysis. Factor scores are weighted averages based upon relative factor loadings for variables on a particular factor. A separate score for each factor in the solution was calculated for each subject. Factor scores (which are Z-scores) were converted to "SAT" scores with fixed means (SDs) of 500 (100). Scores were scaled such that higher scores reflect better performance on each factor. Factor scores were then subjected to further analyses as dependent measures in order to examine their validity as constructs.

Factor scores were compared between two teacher-rated groups of children (attention/behavior disordered and nonhyperactive control). This was done with a t-test for each factor score by the two groups. Partial correlations controlling for age were also run between CTQ scores and factor scores in order to examine whether teacher ratings of attention/behavior disorder were related to these factor scores.

Finally, signal detection measures of d' and ß were calculated for CPT performance of all subjects, and were subjected to t-tests to determine whether there were group differences in perceptual sensitivity or response bias between attention/behavior disordered and normal children. These measures were also subjected to partial correlations (controlling for age) with teacher behavior ratings.

Results

Separation of Attentional Factors

The original predictions were that CPT measures would break down into factors which represent sustained attention (speed/consistency measures) and behavioral control (accuracy measures). These factors were presumed to be independent of each other and of other tests of intelligence and attention. Means (SDs) for the entire sample of the variables subjected to factor analysis are presented in Table 2.

Table 2. Descriptive Statistics on Factor Analysis Variables (n=72)

	Mean	SD
CPT Hits	36.49	3.84
CPT Hit RT	703.43 (msec)	131.91
CPT Hit RTSD	153.84 (msec)	62.32
CPT FA	7.78	11.66
TDT Total	48.93	11.66
PPVT Raw Score	91.57	19.79
Digits F+B	6.78	3.63
MFFT Impulsivity*	500.07	168.67

* Z scores converted to SAT scores

The results of the factor analysis largely confirm the original prediction. A four factor solution was obtained, accounting for 72.8% of the variance. Factor 1 contained significant loadings from CPT Hit RT and RTSD, and accounted for 23.8% of the variance. Thus, it is comprised of measures of CPT response speed and consistency, and may reflect sustained attention or effort. Only CPT FA loaded significantly on Factor 2, accounting for 18.4% of the variance. It may be related to behavioral control, although interpretations from single factor loadings are difficult. Factor 3 contained loadings from CPT Hits and PPVT, accounting for 16.5% of the variance. It may be related to verbal abilities and verbal mediation of attention. Finally, Factor 4 was comprised of loading from Digits F+B and MFFT Impulsivity, and accounted for 14.0% of the variance. Factor 4 is not a CPT factor, but may be related to cognitive impulsivity. The Varimax rotated factor matrix is presented in Table 3.

Table 3. Varimax Rotated Factor Matrix on Attentional and Cognitive Measures **

Variable	Factor 1	Factor 2	Factor 3	Factor 4
CPT Hits	-0.1723	-0.1861	0.5705*	0.0490
CPT Hit RT	0.7301*	-0.1529	-0.0565	-0.0631
CPT Hit RTSD	0.8868*	0.3002	-0.2306	0.1099
CPT FA	-0.1680	0.8532*	-0.0827	0.0985
TDT	-0.1044	-0.2735	-0.0154	0.0905
Digits F+B	-0.0254	0.1043	-0.1359	0.4959*
PPVT Raw Score	-0.0318	0.1139	0.6562*	-0.0982
MFFT Impulse	-0.0466	0.2850	-0.1383	-0.6623*
	Speed/ Consistency	Behavioral Control	?Verbal Mediation	?Cognitive Impulsivity

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* Factor loadings) 0.45

**Raw scores normalized for age by Z-score transformation

Group Differences in Attention and Behavior

Hyperactive vs. nonhyperactive. Comparisons between attention/behavior disordered (hyperactive) and nonhyperactive controls were performed on the cognitive and attentional measures which were used in the factor analysis. Initial analyses found that hyperactives detected fewer targets overall on the TDT [$t(70)=1.96$, $p<.05$]. There were trends towards increased RT variability [$t(70)=-1.81$, $p<.07$] and increased FA [$t(70)=-1.75$, $p<.08$]. There were no group differences for CPT hits, RT, PPVT, digit span, or MFFT Impulsivity scores.

As the CPT measures are highly age dependent, the above analyses were repeated controlling for age. Table 4 contains the age-adjusted means for the variables subjected to factor analysis for the two groups. When data were subjected to Analyses of Covariance (ANCOVA) with age as the covariate, the hyperactive and control subjects did not differ significantly on any measure. There was a trend towards fewer hits in the hyperactive group, but no other attentional or cognitive variable distinguished the groups.

Table 4. Age-adjusted Mean (SD) of Variables in Factor Analysis Broken Down by Group

	Controls (n=51)	Hyperactives (n=21)
CPT Hits*	36.94 (2.88)	35.3 (5.31)
CPT Hit RT	702.42 (133.93)	705.88 (128.98)
CPT Hit RTSD	147.79 (62.79)	168.52 (57.55)
CPT FA	6.45 (10.85)	11.0 (12.97)
TDT Total	49.69 (9.23)	47.08 (9.12)
PPVT Raw Score	91.58 (20.89)	91.54 (16.77)
Digits F+B	6.77 (3.9)	6.8 (2.96)
MFFT Impulsivity	485.7 (173.85)	534.97 (154.38)

****

* p<.08 (trend)

As no individual attentional or cognitive measure distinguished the groups, the dimensional factor scores were examined. To test the validity of the factor scores as measures of attention and behavior, they were compared between the hyperactive and nonhyperactive groups. Table 5 contains the means (SDs) of the factor scores for the two groups.

There was a trend for diminished behavioral control (Factor 2) in hyperactives compared to controls [t(70)=1.77, p<.08]. No group differences emerged in speed/consistency (Factor 1) [t(70)=1.08. p>.10], verbal mediation (Factor 3) [t(70)=.87, p>.10] or cognitive impulsivity (Factor 4) [t(70)=.49, p>.10] (t-tests rather than ANCOVAs were used since these variables were already normalized for age).

Table 5. Means (SD) on Factor Scores* by Groups

	Controls (n=51)	Hyperactives (n=21)
Factor 1	507.81 (92.014)	481.14 (102.781)
Factor 2 **	511.81 (87.471)	471.33 (89.487)
Factor 3	505.002 (74.27)	487.851 (80.294)
Factor 4	502.873 (78.456)	493.022 (73.083)

****

* Factor Scores transformed to SAT scores

** $p < .08$

"Research" hyperactives vs. nonhyperactives. In order to compare the IOWA research and clinical criteria, a subgroup of hyperactives was selected by the IO criterion of 11. It was hypothesized that if Factor 2 was related to behavioral control, a more severely disturbed sample of children would highlight the effect despite a smaller sample size. This was indeed the case. "Research" hyperactives (n=12) had significantly lower behavioral control scores than controls (n=51) [$t(61)=2.03$, $p<.05$]. There were no significant differences between the groups on the other three factor scores when the research criteria were used to define the hyperactive group. Means (SDs) of this group on descriptive variables and factor scores are presented in Table 6.

Table 6. Mean (SD) of Descriptive Variables and Factor Scores in the "Research Hyperactive" Group

(n=12)

Variable	Mean	SD
Age	8.79	1.56
PPVT Standard	85.17	11.33
Factor 1	460.28	98.21
Factor 2*	453.57	97.33
Factor 3	467.61	61.61
Factor 4	503.31	80.82

****

* differs from Control group; $p < .05$

Relationships between Attention & Behavior Ratings

Further validation of the Factor scores was obtained by correlating them with teacher ratings of behavior. In order to assess the efficacy of using the CTQ factors as dependent measures, initial analyses involved Pearson correlations on the CTQ Hyperactivity, Conduct Problems and Inattention/Passivity factors. Despite the fact that they are derived from different questions on the CTQ (see Appendix B), all three were substantially intercorrelated in this sample. However, the relationships between these correlations were different in the hyperactive and nonhyperactive groups. Table 7 contains the correlations between the CTQ factors for the entire sample, the control group and the hyperactive group.

Table 7. Intercorrelation between CTQ Factors

	Entire Sample	Control Group	Hyperactive Group
	(n=72)	(n=51)	(n=21)
HYP:CON	0.837 (p=.001)	0.607 (p=.001)	0.688 (p=.001)
CON:IN/PASS	0.653 (p=.001)	0.438 (p=.001)	0.159 (p=.25)
HYP:IN/PASS	0.675 (p=.001)	0.222 (p=.06)	0.116 (p=.31)

****

Key to Abbreviations:

CON: Conduct Problems Factor
HYP: Hyperactivity Factor
IN/PASS: Inattention/Passivity Factor

As can be seen, only Conduct Problems and Hyperactivity are substantially intercorrelated in the hyperactive group. In the control group, Conduct Problems is strongly intercorrelated with Hyperactivity as well with Inattention/Passivity. This suggests that Conduct Problems and Hyperactivity overlap as dimensions, and that this overlap is true for hyperactive as well as nonhyperactive children. In other words, children who are rated as hyperactive by their teacher are very likely to demonstrate difficulties in the area of conduct control and vice versa. In the neither group were the Hyperactivity and Inattention/Passivity factors correlated. This suggests that they may indeed be independently rated dimensions of behavior.

The correlations above suggest that the rating scale dimensions may be sufficiently independent to test between groups as dependent measures. Thus, the four factor scores generated from the present factor analysis were correlated with the Conners factors. Partial correlations (controlling for age) were calculated. Table 8 contains these correlations for the entire sample, and Table 9 contains the correlations for the two separate groups.

The original predictions were that the behavioral control factor would correlate with teacher ratings of behavior problems, and that the speed/consistency factor would not correlate with ratings of disordered behavior or attention. No specific predictions were made regarding the other two factors.

Table 8. Correlation of Factor Scores and Behavior Ratings (Controlling for Age)

(n=72)

	Factor 1	Factor 2	Factor 3	Factor 4
CON:	-0.107 (p=.19)	-0.318 (p=.003)	-0.150 (p=.11)	-0.013 (p=.45)
HYP:	-0.084 (p=.24)	-0.330 (p=.002)	-0.164 (p=.09)	-0.026 (p=.42)
INN/PASS:	-0.124 (p=.15)	-0.239 (p=.02)	-0.273 (p=.01)	-0.095 (p=.21)

****

Table 9. Correlation of Factor Scores and Behavior Ratings by Group (Controlling for Age)

A. Control Group (n=51)

	Factor 1	Factor 2	Factor 3	Factor 4
CON:	-0.181 (p=.11)	-0.234 (p=.05)	-0.270 (p=.03)	-0.162 (p=.13)
HYP:	0.077 (p=.30)	-0.312 (p=.01)	-0.133 (p=.18)	-0.019 (p=.45)
INN/PASS:	-0.002 (p=.50)	-0.186 (p=.10)	-0.266 (p=.03)	-0.065 (p=.33)

****

B. Hyperactive Group (n=21)

	Factor 1	Factor 2	Factor 3	Factor 4
CON:	0.151 (p=.26)	-0.267 (p=.13)	0.090 (p=.35)	0.351 (p=.07)
HYP:	-0.035 (p=.44)	-0.226 (p=.17)	-0.155 (p=.26)	0.183 (p=.22)
INN/PASS:	-0.142 (p=.28)	-0.003 (p=.49)	-0.316 (p=.09)	-0.087 (p=.36)

****

As can be seen, when the entire sample was considered, Factor 2 (behavioral control) is significantly correlated with teacher ratings of attention and behavior problems. These relationships held up when the sample was divided into groups. In the nonhyperactive control group, behavioral control was significantly correlated with Conduct Problems and Hyperactivity, but not Inattention/Passivity. The magnitude and direction of the correlations in the hyperactives suggests the same relationships as seen in the controls, although the small sample size precluded significant p values. For both groups therefore, good behavioral control is associated with decreased symptomatology on teacher ratings of conduct problems and hyperactivity.

Interestingly, Factor 3 (Verbal Mediation) was significantly related to the Inattention/Passivity factor of the CTQ in the entire sample (p=.01), the controls (p=.03) and almost reached significance in the hyperactives (p=.09). This supports the contention that Factor 3 (again, comprised of CPT hits and PPVT score) indeed reflects an attentional substrate, possibly involving language, which is not reflected by CPT performance alone. Factor 4, for which no specific predictions were made, correlated significantly with Conduct Problems in the hyperactive, but not in the control group. This suggests that it may be related to some form of impulsivity.

Signal Detection Measures

With a signal detection analysis of the CPT variables, a trend suggested that hyperactives had lower perceptual discrimination abilities (d' values) [$t(70)=1.81$, $p<.06$]. There was no difference in response bias (ß) between the groups [$t(70)=-1.05$, $p>.10$]. However, when age was used as a covariate, the trend towards lower d' in hyperactives disappeared [$F(1,69) = 2.31$, $p>.10$], suggesting instead that signal detection parameters are highly age dependent. Age adjusted means (SDs) for signal detection measures are found in Table 10.

Table 10. Signal Detection Measures by Group

		Controls (n=51)	Hyperactives (n=21)
d'	Mean (SD)	3.74 (0.706)	3.37 (0.821)
	Age adjusted	3.72	3.45
ß	Mean (SD)	3.47 (2.887)	4.41 (4.578)
	Age adjusted	3.55	4.21

Signal detection measures of d' and ß were also subjected to correlational analysis. Partial correlations were performed with the CTQ factors (controlling for age since the analyses above determined age was a significant covariate). These correlations are presented in Table 11. Perceptual sensitivity (d') was significantly related to both rating scale measures of attention: the Hyperactivity and Inattention/Passivity factors. It was not related to Conduct Problems. Decision bias (β), which is thought to reflect impulsivity, was not related to any teacher rating of problem behavior. This, along with the lack of significant group effects in β in the previous analyses, casts doubt onto the adequacy of response bias as a valid measure of impulsivity in children. Perceptual sensitivity, on the other hand, has partial support as a valid attentional parameter, however the lack of significant group effects makes interpretation difficult.

Table 11. Correlation of Signal Detection Measures With Behavioral Ratings (controlling for age)

(n=72)

	d'	β
CON:	-0.129 (p=.14)	-0.135 (p=.13)
HYP:	-0.216* (p=.04)	-0.078 (p=.26)
IN/PASS:	-0.256* (p=.02)	0.096 (p=.21)

****

Discussion

These data support many of the initial predictions of Experiment 1. The factor analysis demonstrated that many commonly used tests of attention are separable into distinct attentional subfactors. Two of these factors replicate the findings of the pilot studies, which had suggested separation of CPT measures into speed/consistency (sustained effort) and accuracy (behavioral control) components. This parallels Factors 1 and 2 of the present study.

Factor 1 was interpreted to reflect sustained effort, as it was comprised of measures of CPT response speed and consistency. The ability to maintain rapid, even responding through the duration of lengthy detection tasks is related to the ability to resist fatigue, and to marshall attentional abilities over time. This is thought to underlay sustained attention.

The lack of significant differences between hyperactives and controls on Factor 1, and the fact that it did not correlate with any teacher rating of problem behavior further supports the notion that it involves effortful output. The output abilities involved in rapid and consistent performance alone may not be deficient in hyperactives. These are also not the only factors which go into good vigilance performance.

On the other hand, Factor 2 (CPT false alarms) may be more closely related to behavior problems. A trend supported the prediction that hyperactive children have poorer behavioral control (or at least, lower scores on the factor believed to reflect behavioral control) than nonhyperactive controls. The utility of the factor score as opposed to simply the measure of FA is evidenced by the fact that there was no group difference at all on false alarms alone. It was the weighted average of that score with the other variables in the analysis which approached significance.

When a more stringently defined subset of hyperactive children was selected, this factor reached significance. This result provides concurrent validity for the notion that Factor 2 is related to behavioral control.

That a significant finding emerged with a smaller, more symptomatic subsample suggests that the concept of behavioral control is somewhat confounded by diagnostic and behavioral heterogeneity. While alleged to be more homogeneous than the clinically defined hyperactives (Loney & Milich, 1982), the "research" hyperactive group may have included children with more generalized problems of dyscontrol. This groups would be expected to have more difficulties in behavioral control, whether they were hyperactive or not. Cleaner diagnostic groups may be required to highlight the precise nature of this factor, and to determine the utility of the separation of behavioral control and sustained attention. One further note of caution is that Factor 2 was comprised of a single factor loading. Interpretation from single loadings is speculative in the absence of supporting evidence.

That supporting evidence was provided by the correlations of Factor 2 with teacher ratings. Poor behavioral control and ratings of problem behavior in the classroom were substantially correlated, however behavioral control and Inattention/Passivity were not correlated. This was the case for nonhyperactive controls and hyperactives (although in the latter case, this was evidenced by the magnitude but not the p value of the correlation coefficients).

These relationships were to be expected in light of the fact that the Hyperactivity and Conduct Problems factors are comprised of questions pertaining to overactivity, aggressivity and dyscontrol. Behavioral control on the CPT would be expected to correlate substantially with those dimensions. On the other hand, the Inattention/Passivity Factor of the CTQ does not rate difficulties with dyscontrolled behavior.

The other two factors generated by the factor analysis are less clear. Factor 3 (comprised of PPVT and CPT Hits) relates verbal abilities as well as vigilance. This was not predicted, as CPT performance and intelligence were expected to be unrelated. The significant correlation of Factor 3 with CTQ Inattention/Passivity supports the possibility that CPT Hits is a measure less involved with overt control of responding and behavior (e.g. output) than the first two factors. It may be related to learning and cognitive ability, perhaps involving verbal mediation of attentional performance. Clearly, more goes into good vigilance performance than consistency and restraint.

Factor 4 was the only factor which did not load any CPT variable. The MFFT Impulsivity score is thought to measure a reflectivity/impulsivity score, and the Digit Span test is generally believed to be a measure of short term memory which is sensitive to attentional fluctuations. In these analyses, impulsivity is related to poor digit span, and reflectivity (negative MFFT Impulsivity scores) is related to good span. Thus, good performance on this very commonly used WISC-R subtest may be more sensitive to difficulties in control of impulsive responding than decreased attention or poor memory skills. The possibility that this factor is related to impulsivity is supported by the correlation between Factor 4 and Conduct Problems in hyperactive, but not control, subjects.

It is interesting that MFFT was independent from the presumed CPT measure of impulsivity. This may reflect a dichotomy of behavioral control versus cognitive control on attentional tasks. Thus, problems of "impulsivity" or "inattention" might exist at behavioral or cognitive levels, and there is no reason to assume that deficit in one particular subcomponent implies deficit in any other. The existence of a non-CPT related impulsivity factor strengthens the contention that behavioral control of impulsivity is a critical ingredient in attentional performance.

The utility of these analyses comes from the fact that no CPT variable alone differentiated the groups. There were no differences in hits, hit RT, RT variability, FA, d' or ß when age was controlled. It was the dimensional factor scores which distinguished the performance of the two groups. Moreover, the separability of several commonly used attentional tests into independent factors suggests that the interchangeable use of these tests as "attentional tasks" is unwarranted. They appear to be measuring different attentional subprocesses.

The issue of age-control bears comment. Several of the measures used here were strongly intercorrelated with age, and several significant effects were lost when age was covaried. Age adjustment may be a critical factor in analyzing CPT data, which has often been overlooked. Clearly CPT studies which do not take this into account must be interpreted cautiously.

In sum, these analyses demonstrate that various tests of attention measure distinct functions related to behavioral and cognitive control. Some, but not all measures appear to be related to behavior problems in children. Moreover, these different measures of attention are not interchangeable. The CPT variable most clearly related to behavior problems in children was the dimensional factor which includes false alarms, not the speed/consistency factor. Experiment 2 addressed the relationships between errors and speed, especially performance over time, in order to further examine similarities and differences in attentional performance in hyperactive and nonhyperactive children.

EXPERIMENT 2: Sustained Attention & Change over Time

Sustained attention is defined as the capacity to maintain attention over time. Its assessment often involves the use of vigilance or continuous performance tests (CPTs), which require the subject to monitor a repetitive series of stimuli and respond to the presence of infrequent targets. The vigilance measure is usually response accuracy (e.g. number of targets detected and/or errors) or reaction time (RT). While the CPT is commonly used as a measure of sustained attention in children, the degree to which CPT performance varies as a function of time has not been extensively explored.

Studies examining CPT performance in hyperactives over time were discussed above. Sykes and colleagues (1973) demonstrated decreased hits and increased errors with time on task in hyperactives. Michael, et al. (1981) were unable to show differential deterioration with time in hyperactives relative to normal children. Neither of those studies however measured RT, which, along with accuracy, is important in the evaluation of performance decrement over time. Two recent studies of RT and accuracy changes over time were unable to demonstrate sustained attention deficits in hyperactive children (Schachar, Logan, Wachsmuth and Chajczyk, 1988; van der Meere & Sergeant, 1988b).

The former study compared hyperactives, children with other diagnoses (including learning disability, emotional disorders, conduct disorder and mixed hyperactive/conduct disorder), and normal controls on three versions of the CPT. They explored the ability of children with various diagnoses to a) prepare attention to warning signals, and b) maintain attention over time. Their predictions were that the attention disordered (hyperactive) subjects would have difficulties in both of these areas, consistent with the notion that they have specific deficits in sustained attention (Schachar, et al, 1988). They also asserted that this deficit should be statistically visible as an interaction between diagnostic group and time on task.

Using measures of hit percent, false alarm percent and RT for hits, those authors found that <u>all</u> children deteriorate over time and improve with the opportunity to prepare attention (Schachar, et al., 1988). This nonspecific effect of time on task was measured as decreased RTs and hits over the first half of the 12.5 minute task relative to the second half. No Group X Time interaction was found, nor was a main effect for Group found, which would show that hyperactives were generally less accurate than controls. The authors concluded that a sustained attention deficit does not distinguish hyperactives from other disordered children or normals (Schachar, et al., 1988).

The second study utilized more complicated theories and procedures to evaluate sustained attention in hyperactives (van der Meere & Sergeant, 1988b). A brief discussion of their reasoning will be helpful. Following Shiffrin and Schneider's (1977) model of controlled versus automatic processing, van der Meere and Sergeant characterized sustained attention as a controlled process. Control processes in the original model are closely allied with pools of energy available for information processing (Shiffrin & Schneider, 1977; Schneider & Schiffrin, 1977; Eysenck, 1982). Sustained attention is required for tasks which involve controlled processing but less so for automatic processing. Thus, van der Meere and Sergeant construed deficits in sustained attention as deficits in controlled processing.

It has been suggested that the vigilance decrement may result from decreased sensitivity (d', as discussed above) or changes in response criteria (ß) (Parasuraman & Davies, 1977; Parasuraman, 1984). Sanders (1983) suggested that d' is related to arousal and ß related to activation. That is, the subject's perceptual/discriminatory abilities (input abilities) are closely allied to arousal level, and response bias (an output measure) is dependent upon activation (Sanders, 1983; Eysenck, 1982; Posner, 1973; van der Meere & Sergeant, 1988b). It has been further asserted that performance changes over time may be related to fluctuations in the allocation of processing effort to each of those input/output functions (Sanders, 1983).

Putting all of these models together, van der Meere and Sergeant concluded that deficits in d' over time would reflect dysfunction in the arousal/input stage of processing, whereas decline in ß over time would reflect deficiencies in activation/output over time (van der Meere & Sergeant, 1988b). They, like Schachar, stated that statistical interaction between a target group and task duration was necessary to test for sustained attention deficits within that target group. Because the theory rested on signal detection parameters, those measures were calculated over time periods on a complicated memory/visual search task. Thus, hyperactive subjects were expected to show decrements in both d' and ß over time relative to normals (van der Meere & Sergeant, 1988b).

van der Meere and Sergeant were unable to demonstrate that interaction. They found, like many other studies discussed above, that hyperactives had a lower perceptual sensitivity than normals (effect of Group) and that d' diminished with time on task (effect of Time). However, there was no Group X Time interaction, nor did they demonstrate that ß deteriorated with time (van der Meere & Sergeant, 1988b). Thus, this study also failed to demonstrate a deficit in sustained attention deficit in hyperactive children.

Signal detection analysis has already been discussed. The use of this analyses in CPT paradigms has become popular (O'Dougherty, et al., 1984; Nuechterlein, 1983; Zelko, 1986; van der Meere & Sergeant, 1988b). However, Experiment 1 of the present study failed to find group differences in either d' or ß when age was controlled, suggesting that age-effects are responsible for some of the differences in perceptual sensitivity reported. This has not generally been addressed in studies which utilize these measures.

Another problem with the use of signal detection analysis to examine sustained attention is the use of accuracy and decision bias, but not RT measures. Signal detection measures alone thus do not provide definitive evidence of sustained attentional processes. It has also been shown recently that false alarms may not reflect a unitary process (Halperin, et al., 1988). As false alarm rate is used in the calculation of d' and ß, valuable information regarding separability of error subtypes may be lost by compressing commission errors into a single measure. To the extent that signal detection theory was designed to account for perceptual and decision components in detection tasks, it may not be an appropriate means of evaluating CPT-derived sustained attentional processes.

Perhaps a more appropriate way to delineate sustained attention differences in hyperactives is to look at relationships between speed and accuracy, in particular, the speed-accuracy-tradeoff (SATO). In RT tasks, subjects are usually encouraged to work as quickly and accurately as possible. This is also the case in many (but not all) CPT procedures. These goals, however, may be incompatible. A subject may either tolerate many errors (as a tradeoff for speed), or perform the task slowly (as the price for accuracy). The SATO is a hypothetical construct, which holds that under certain conditions, a subject performing a speeded detection task may choose to sacrifice a speedy performance for an accurate one or vice versa.

SATOs may be measured several different ways. They may be graphed as successive points representing mean hit RT and mean accuracy per unit time (Sperling, 1984). This is a complicated function of the classic Performance Operating Character (POC), which is a curve representing the performance of the ideal detector (Hirst, 1986; Sperling, 1984). However, the details of that model are not germane to this discussion. Sergeant and Scholten (1985) have suggested that the correlation between the percentage of errors and the latency of correct response is another way to measure this function. Negative correlations between error percentage and speed indicate SATOs (Lachman, Lachman & Butterfield, 1979; Sergeant & Scholten, 1985; van der Meere & Sergeant, 1988a). Along with high error rates, evidence of the SATO is often interpreted as impulsive responding (van der Meere & Sergeant, 1988a). Thus, the adoption of a fast, error-prone response strategy (SATO) might characterize the performance of hyperactive subjects on these tasks.

The predictions relating speed and accuracy which would follow such reasoning parallel the "fast-guess" model (Ollman, 1966; Yellot, 1971). In that model, correct processing of stimulus characteristics is presumed to take time. Detection decisions which occur quickly are presumably initiated before processing has been finished--they are essentially guesses before stimulus identity could have been established (Yellot, 1971; Sergeant & Scholten, 1985; Sperling, 1984). Put another way, fast responding based upon incomplete information may lead to high error rates, while slow responding to stimulus characteristics leads to low error rates. The model presumes that the frequency of guesses and stimulus controlled responses is highly subjective (Yellot, 1971).

Sergeant and Scholten tested the fast-guess model in hyperactive children, under the assumption that fast-guess prone responding was indicative of an impulsive style (Sergeant & Scholten, 1985). The study employed letter-identification tasks where both "yes" responses to targets and "no" responses to nontargets were required on tasks of increasing difficulty. Instructions to subjects either emphasized speed, accuracy or both. They compared normal, hyperactive and distractible but nonhyperactive children. There were many findings, but the key one for this discussion was that hyperactive children were not able to increase the speed of their performance according to the demands of instructions to do so, although the accuracy of their performance declined. They apparently sacrificed both speed and accuracy. Instructions which should induce SATOs did not affect the RT performance of the hyperactive group, although the other two groups were able to make the appropriate adjustments (Sergeant & Scholten, 1985). The fast-guess model only moderately predicted the performance of the hyperactive subjects in that study, in that hyperactives had a large proportion of both fast and slow errors. The performance of nonhyperactive children was strongly predicted by the model (Sergeant & Scholten, 1985).

Taken together, findings such as these suggest that hyperactive children do not demonstrate the same relationship between speed and accuracy as nonhyperactive children. The precise nature of this relationship has not been explored fully. The results of Sergeant and Scholten suggest that hyperactive children may not demonstrate impulsive responding as predicted by the fast-guess model, but that nonhyperactive children do. Thus, hyperactives may suffer from control deficits which do not permit modulation of RT performance in accordance with task goals.

High error rates may be a separate function from RT in these children, and may need to be explored in a different manner.

Clearly, it remains to be shown that hyperactive children have deficits of sustained attention and impulsivity. Previous studies have been unable to demonstrate this for various reasons, many of which have already been discussed. The two studies discussed above rectified some of the original problems by using RT data in evaluating performance changes over time on attentional tasks (Schachar, et al., 1988; van der Meere & Sergeant, 1988b). Still, those studies were unable to show that hyperactive children have unique deficits in sustained attention which appear as deficiencies in performance speed and accuracy over time. Moreover, it is important to control or correct for baseline performance levels, as hyperactives are often found to be both slower and less accurate than normal children on these tasks (Sykes, et al., 1971; Sykes, et al., 1973; Michael, et al., 1981; Klee & Garfinkel, 1983; Nuechterlein, 1983; O'Dougherty, et al., 1984; van der Meere & Sergeant, 1988b). Thus, in addition to a differential group X time interaction, the rate of decrement rather than the presence of decrement itself may be important in demonstrating differences in sustained attention between hyperactives and other children.

Experiment 2 aimed to examine sustained attention in non-referred school age children. It was designed to examine changes over time in CPT measures of speed/consistency and behavioral control. The broad aim was to determine whether non-referred hyperactive children have deficits in sustained attention. It was hypothesized that hyperactive but not normal children will be unable to maintain rapid, accurate performance over the duration of the task. The following specific predictions were made:

1. As putative measures of sustained attention, RT and RT variability will deteriorate over time in both hyperactive and nonhyperactive children.
2. Measures of accuracy (false alarms and hits) will deteriorate over time in hyperactive but not nonhyperactive children, evidencing deficits in behavioral control.
3. Speed/accuracy relationships will differentiate hyperactive and nonhyperactive groups. Hyperactive children will not be able to trade speed for accuracy, that is make SATOs. This will be seen as positive or absent correlations between errors and latency for hits (RT) in the hyperactive group.
4. The "fast-guess" model predicts that impulsive errors occur in children with fast hit RT and inattentive errors occur at slow RTs. This model will also differentiate the groups, with hyperactives

making more impulsive errors than nonhyperactive children.

Method

Subjects

Subjects were unselected children (grades 1 through 6) from the same parochial school as in Experiment 1. This school was used again so as to approximate the same racial, ethnic and socioeconomic sampling as the previous study. A total of 73 students participated in the study. There were 32 boys and 41 girls, with a mean (SD) age of 9.56 (1.81) years). Although socioeconomic data were not individually determined, the children were predominantly from a lower SES. The majority of the children were Hispanic (62 percent) or black (34 percent). All subjects were English speaking. In order to ensure that there were no mentally deficient children in the sample, a minimum IQ score of 70 was required for participation. Additionally, the Wide Range Achievement Test-Revised (WRAT-R) was administered as a measure of academic ability. Table 11 contains the means (SD) of the descriptive variables for the entire sample.

Table 11. Mean (SD) of Descriptive Variables

(n=73)

	Mean	SD	min. - max.
Age	9.56	1.81	6.3-14
FSIQ	99.90	13.84	71-143
WRAT-R Reading	95.56	14.50	60-129
WRAT-R Arithmetic	97.66	16.01	64-155

****

The procedures for recruiting the sample were identical to those utilized in the previous study. A cover letter and consent form were sent to parents of all children attending the school. Teachers completed the Revised Conners Teacher Questionnaire (CTQ) for all children who had parental permission to participate in the study. This scale was described in Experiment 1.

Children were divided into two groups based upon the Inattention/Overactivity (IO) scale of the IOWA Conners Teacher Questionnaire (Loney & Milich, 1982). Children with IO scores greater than 7 were considered to meet criteria for hyperactivity. Children with scores below 7 were not considered hyperactive, and served as controls. Rating scale data was unavailable on one child.

The IOWA Conners resulted in a hyperactive group of 22 students (11 boys and 11 girls). The nonhyperactive control group contained 50 children (21 boys and 29 girls). The two groups did not differ in age [$t(70)=1.65$, $p>.10$], intelligence [$t(70)=.14$, $p>.10$], and reading ability [t(69)=0.39, p>.10]. There was a trend towards lower arithmetic ability in the hyperactive group [t(70)=1.77, p<.08]. Table 12 contains the means (SD) of both groups on descriptive measures.

Table 12. Mean (SD) of Descriptive Measures by Group

	Control (n=50)	Hyperactive (n=22)	p
Age	9.79 (1.49)	9.03 (1.49)	NS
FSIQ	99.92 (14.92)	99.41 (11.50)	NS
WRAT-R Read.	95.82 (14.29)	94.36 (15.30)	NS
WRAT-R Math	100.06 (15.93)	92.92 (15.39)	<.08

****

Procedure

All children were administered a brief neuropsychological and attentional test battery. Two test sessions of approximately one hour each were required. One session was dedicated to intelligence and academic testing, and the other involved attentional testing. The test order within each session was designed to reduce the effects of fatigue, and sessions were counterbalanced to reduce order effects. All tests were individually administered by one of 4 trained examiners. The tests and scales which were administered were:

1. Revised Conners Teacher Questionnaire (CTQ).
2. Wechsler Intelligence Scale for Children-Revised (WISC-R).
3. Wide Range Achievement Test-Revised (WRAT-R).

4. Continuous Performance Test (CPT).

Revised Conners Teacher Questionnaire (CTQ) (Goyette, et al., 1978). This instrument was described in detail in the previous experiment. No variations in administration or scoring were used. The IOWA clinical hyperactivity criterion of 7 was used to form the hyperactive and normal groups. Children scoring greater than 7 were considered to be hyperactive, and children scoring below 7 were used as nonhyperactive controls.

Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974). The WISC-R was administered as a measure of intellectual functioning. Although the PPVT had been used in the previous study, it was felt that the WISC-R would provide more accurate estimates of intelligence. As many other attentional studies utilize WISC-R IQ data, its use renders these data more comparable with that work. Additionally, the high percentage of Spanish speaking children in the sample may have posed problems with the use of an English vocabulary test as the intelligence measure in the previous study.

The WISC-R is well standardized for use with children in the age range used in this study, with a mean of 100 and standard deviation of 15. This test yields separate Performance IQ, Verbal IQ and Full Scale IQ measures. Performance IQ was prorated based upon four of the five subtests that make up that scale (one test was eliminated due to time constraints). Only Full Scale IQ scores were used however, with a minimum IQ cutoff of 70. This ensured that mentally deficient children were not included in the sample.

Wide Range Achievement Test-Revised (WRAT-R) (Jastak & Wilkinson, 1984). The WRAT-R is a commonly used test of academic achievement. It includes three subtests (reading, oral spelling and arithmetic), and is well standardized for use with school-age children and adults. The reading and arithmetic subtests were used in the present study in order to compare groups on academic abilities.

Continuous Performance Test (CPT). The CPT was described above. There were a few modifications, however. In the present version, the frequency of targets ("A" preceding "X") and nontarget foils is 10 percent. The previous version of the CPT had a 10% target frequency, but the frequencies of nontargets ("X" without "A", and "A" without "X") were 5% and 17%, respectively. The current task was modified in an attempt to allow equal likelihoods of three possible false alarms.

Previous work (Halperin, Wolf, Pascualvaca, et al., 1988; Halperin, Wolf & Young (unpublished)) showed that the A-X CPT results in 4 subtypes of commission errors. One group, the so-called "A-not-X" errors occur when subjects respond to letters other than the "X" following the cue letter "A". These errors are associated predominantly with fast RTs and are construed as impulsive errors. Another group, called "X-only" errors occur when the subject responds to the presence of a target which was not preceded by the appropriate cue stimulus. These errors were associated with slower RTs, and were interpreted as inattentive errors, along with missed targets. The relationships between RTs and the other two subtypes ("A-only" where the response is to a cue without an accompanying target stimulus, and "Random" to letters other than "A" or "X") were less clear (Halperin, et al., 1988; Halperin, et al., 1989). One possibility was that the "A-only" errors included instances when the subject responded to the cue without waiting to ascertain whether or not a target would follow. This might be construed as impulsivity.

Thus, the above work suggested that different CPT errors may be associated with different psychological processes. This was explored in the current study by combining different errors into Inattentive ("X-only" + Misses) and Impulsive ("A-not-X" + "A-only) error classes. Thus the CPT measures used in the current study were number of hits, reaction time for hits (hit RT), RT variability (RTSD), total false alarms (FA), total errors (misses plus false alarms), misses, Inattentive errors ("X-only" plus misses) and Impulsive errors ("A-not-X" plus "A-only" errors).

In order to assess performance changes over time, four of these CPT measures (hits, FA, hit RT, and RTSD) were assessed for each 3 minute quarter of the task. Thus, overall measures and quarterly measures were obtained for each child. In order to evaluate SATOs and relationships between errors and RTs, error types were evaluated for groups of children divided by average hit RT ("bins").

Data Analysis

In order to evaluate performance changes over time, 2-way Repeated Measures Analyses of Covariance (ANCOVA) using age as the covariate were conducted. Age was controlled because pilot analyses demonstrated a significant correlation between CPT measures and age. Differences on four performance measures (CPT Hits, FA, Hit RT and RTSD for Group (Hyperactive versus Control) X Time (Quarters 1-4) were evaluated. Significant main effects and interactions were followed by multiple comparisons with the Scheffe test (.05 significance level) to evaluate changes over the test quarters.

Speed/accuracy relationships over time were evaluated by partial correlations (controlling for age) between errors occurring within a CPT quarter and the mean hit RT of that quarter. Negative correlations were interpreted as reflecting SATOs; e.g. an association between slower RTs and good performance (low error rates). On the other hand, positive correlations (high error rates associated with slow RTs) suggested that accuracy was not gained by slowing down.

The fast-guess model was tested by analyzing relationships between error subtypes and RT. Subjects were first divided into four groups, according to percentiles of average hit RT. These groups were called "bins". Bin 1 contained subjects with the fastest average hit RTs (below the 25th percentile). Bin 2 contained children with average hit RTs falling between the 25th and 50th percentiles. Bin 3 was comprised of children with mean hit RTs between the 50th and 75th percentiles. Finally, Bin 4 contained subjects with the slowest average hit RTs, falling above the 75th percentile.

Error types (total errors, false alarms, misses, Inattentive errors, and Impulsive errors) were evaluated for each RT bin. This was done by two-way ANCOVA using age as the covariate. Error types X Bin (1-4) and Group (hyperactive versus control) were evaluated. Significant main effects were followed by multiple comparisons with the Scheffe test (.05 level).

Results

Group Differences in CPT Performance

Prior to investigating changes in CPT performance over time, mean differences in vigilance were examined. When average scores were evaluated by Analysis of Covariance (ANCOVA) with age as the covariate, the CPT performance of the two groups did not differ. Hyperactive and nonhyperactive groups were equivalent in number of hits [$F(1,71)=.134$, $p>.10$], false alarms [$F(1,71)=1.36$, $p>.10$], misses [$F(1,71)=.26$, $p>.10$], hit RT [$F(1,71)=2.08$, $p>.10$], and RT variability [$F(1,71)=.02$, $p>.10$]. Table 13 contains age adjusted means (SD) for both groups on those variables.

Table 13. Age-Adjusted Mean (SD) of CPT Variables by Groups

	Controls (n=50)	Hyperactive (n=22)	p
CPT Hits	36.30 (5.91)	35.80 (5.70)	NS
CPT False Alarms	3.73 (5.05)	5.44 (7.28)	NS
CPT Misses	3.43 (5.51)	4.09 (5.62)	NS
CPT Hit RT	637.87 (103.48)	672.89 (119.61)	NS
CPT RT Variability	165.34 (68.09)	166.47 (63.80)	NS

****

CPT Performance Changes over Time

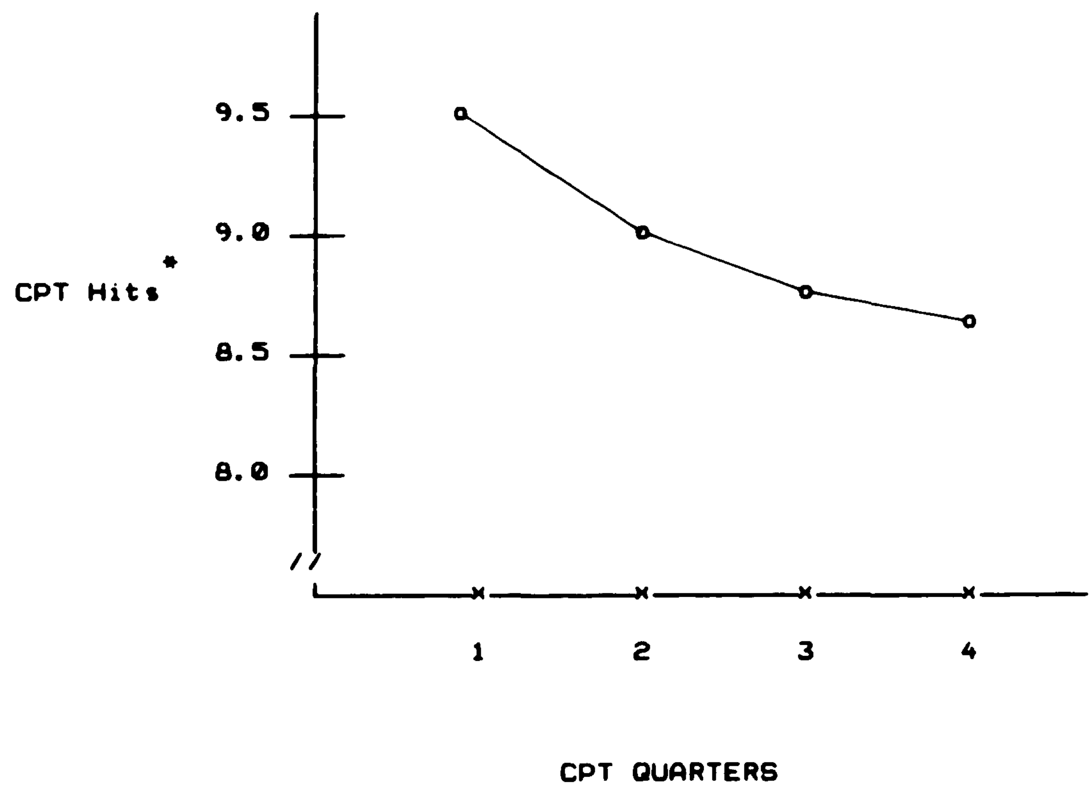
There were two initial predictions regarding performance changes over time. RT and RT variability (presumed measures of sustained attention/effort as per Experiment 1) were expected to deteriorate over time in both hyperactive and nonhyperactive children. Secondly, measures of behavioral control/accuracy (hits and false alarms) were expected to deteriorate in the hyperactive but <u>not</u> nonhyperactive children.

In order to investigate group differences in vigilance decrement, a 2-way Repeated Measures ANCOVA (with age as the covariate) was conducted on four CPT variables. The repeated measure was Time (CPT Quarters 1-4), and the between measure was Group (control vs. hyperactive).

Regardless of Group, significant main effects for Time were found for hits [$F(3,209)=10.439$, $p<.001$], hit RT [$F(3,209)=4.45$, $p<.005$], and hit RT variability [$F(3,209)=11.51$, $p<.001$]. A trend was found for Time for false alarms [$F(3,209)=2.32$, $p<.08$]. Figures 1-4 illustrate the changes in hits, FAs, hit RT and RT variability over the four 3 minute quarters of the task for the entire sample. Age adjusted means (SD) for the entire sample (n=72) are found in Appendix C, Table 1.

Figure 1. CPT Hits Change over Time

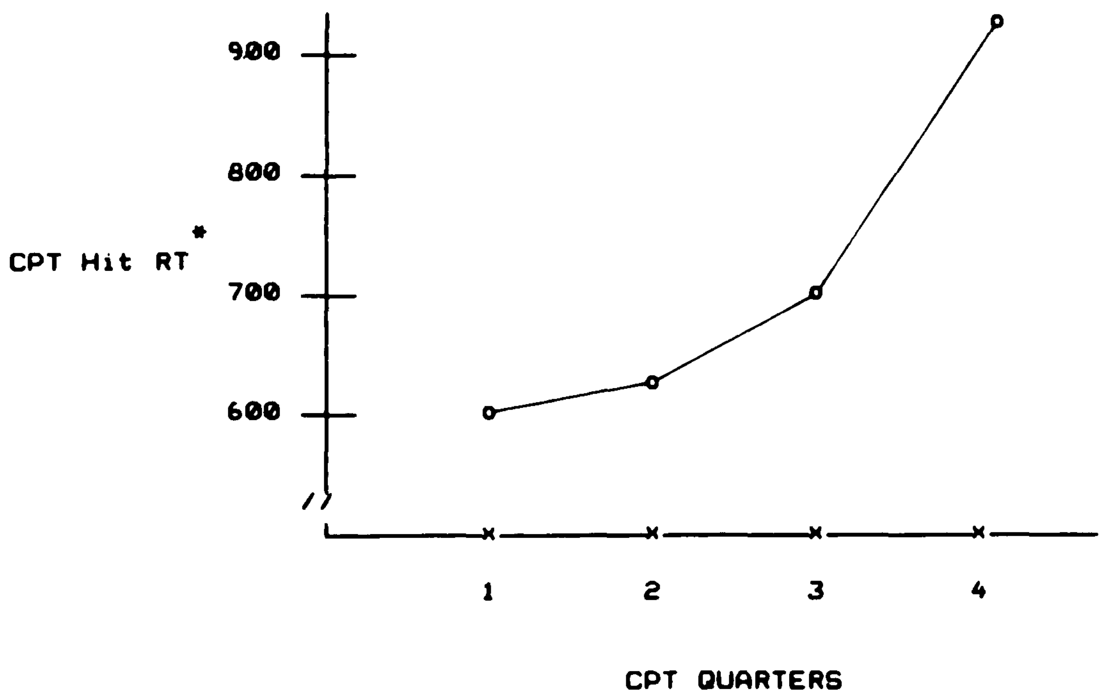
(n=72)



* Quarter 1 > Quarters 2, 3, 4; $p < .05$

Figure 2. Hit RT Change over Time

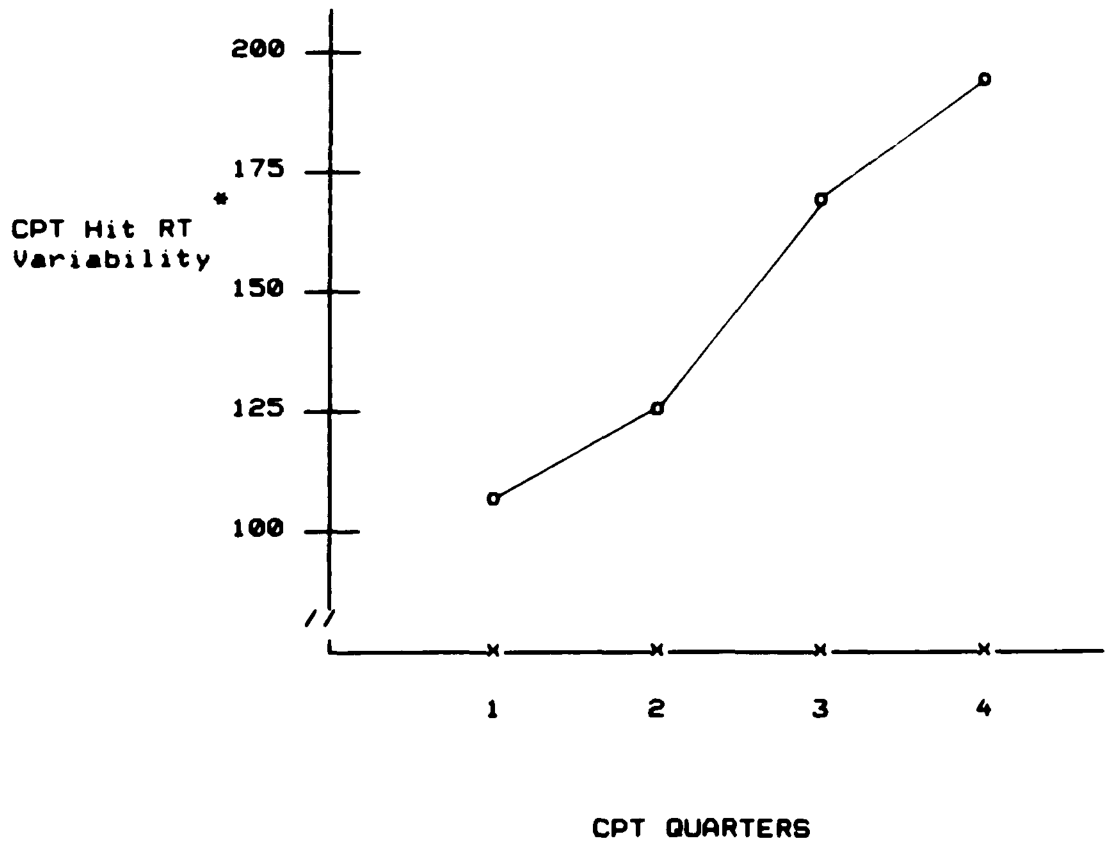
(n=72)



* Quarter 4 > Quarters 1,2; p<.05

Figure 3. RT Variability Change over Time

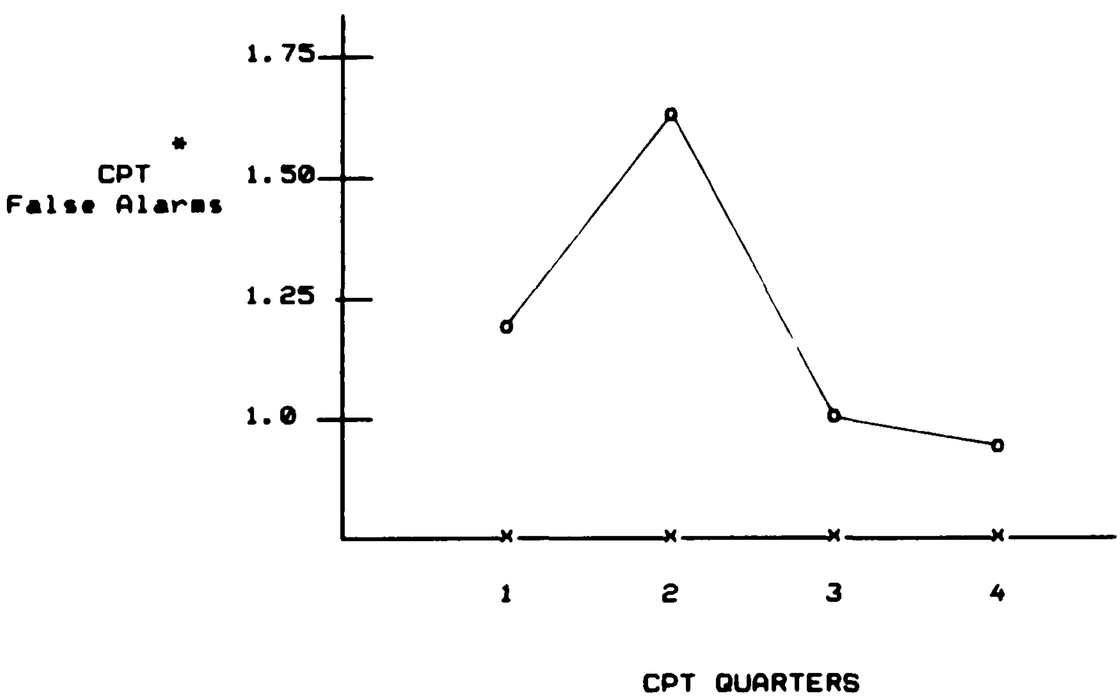
(n=72)



* Quarter 4 > Quarters 1, 2; p<.05

Figure 4. False Alarms Change over Time

(n=72)



* NS trend p<.08

As can be seen in Figures 1-4 above, the significant changes over time for hits, hit RT and RT variability are monotonic. That is, performance declines steadily over the four quarters of the task. Post hoc analyses of the Time effects with the Scheffe test (.05 level) showed that subjects made fewer hits over time. The number of hits in the 1st Quarter was significantly higher than the number of hits in the subsequent Quarters. Reaction time performance also decreased over time. Fourth Quarter hit RTs were significantly slower than 1st or 2nd Quarter RTs. The same relationship was seen for hit RTSD. Subjects performance during the latter parts of the task was significantly more variable than during the early periods. Finally, although there was a trend for false alarms to change over time, the change was not systematic.

Group Differences in CPT Performance over Time

The Repeated Measures ANCOVA showed significant, systematic decrements in CPT performance over time for number of hits, hit RT and RT variability. In order to test the specific predictions of 1) slower and more variable RTs over time for all subjects regardless of group membership and 2) differential decline in accuracy (hits) over time in hyperactives, the analyses were examined for Group main effects and Group X Time interactions. According to the model, RT and RTSD should not interact with diagnostic Group over time, but a Group X Time interaction for hits should occur. The data, in part, support these predictions.

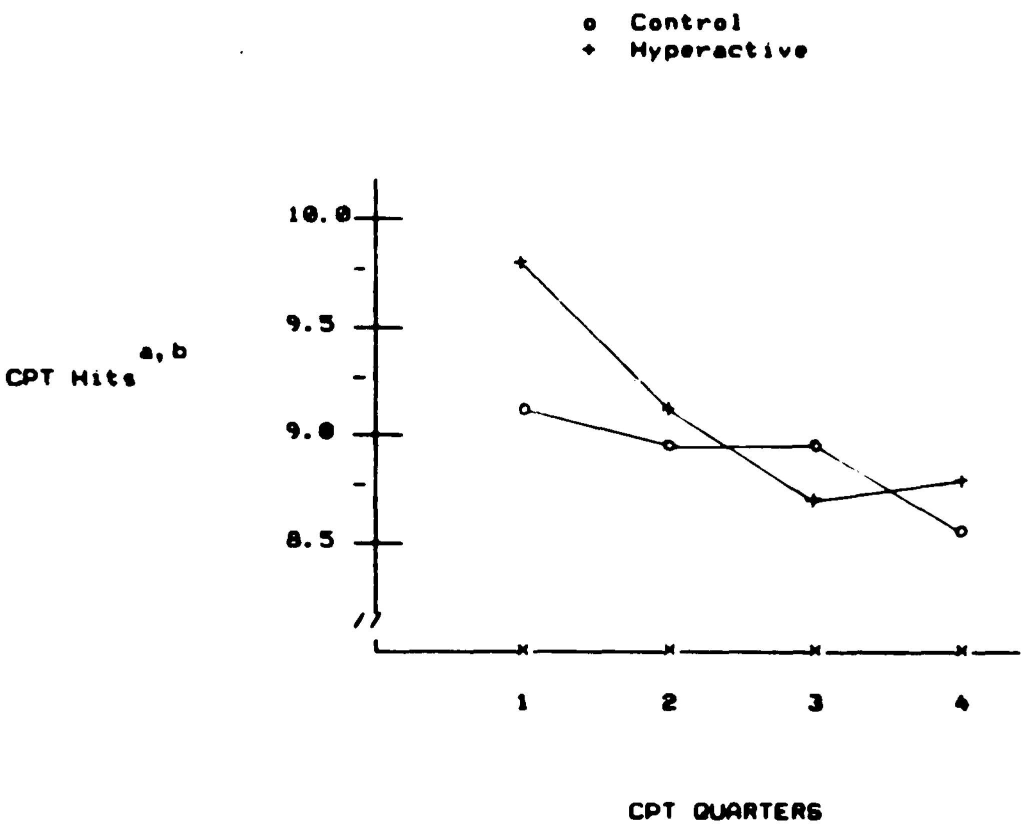
Figures 5-8 show the relationships between CPT variables over time in hyperactive and control subjects. As can be seen, there was a significant interaction between Group and Time for Hits [$F(1,3)=2.871$, $p<.04$]. Post hoc analyses with the Scheffe test (.05 level) revealed that the performance of hyperactives deteriorated over time, while the controls did not. When controlling for age, hyperactives made significantly fewer hits during Quarters 3 and 4 than during Quarter 1. Controls, on the other hand, did not decline over time. The age-adjusted mean hit scores per Quarter show that the hyperactives actually began the task with <u>better</u> hit performance than controls, although this quickly dropped off with task duration.

The data for RT performance are different than predicted. The prediction that all subjects would deteriorate over time was supported by the significant Time effect reported above. There was a significant Group effect [$F(1,69)=4.29$, $p<.04$] however, indicating that hyperactives have generally slower RTs per quarter than control subjects. There was also a trend towards a Group X Time interaction [$F(1,3)=2.52$, $p<.06$]. This suggests that effect of Time was due to the contribution of the hyperactive subjects, whose speed dropped markedly between

Quarters 3 and 4. Hyperactives were slower throughout the task than controls. The rate of decrement was even between the groups until the last quarter, when the mean hit RT of the hyperactives rose sharply. There were no Group or Group X Time effects for RT variability, suggesting that both groups declined over time at the same rate.

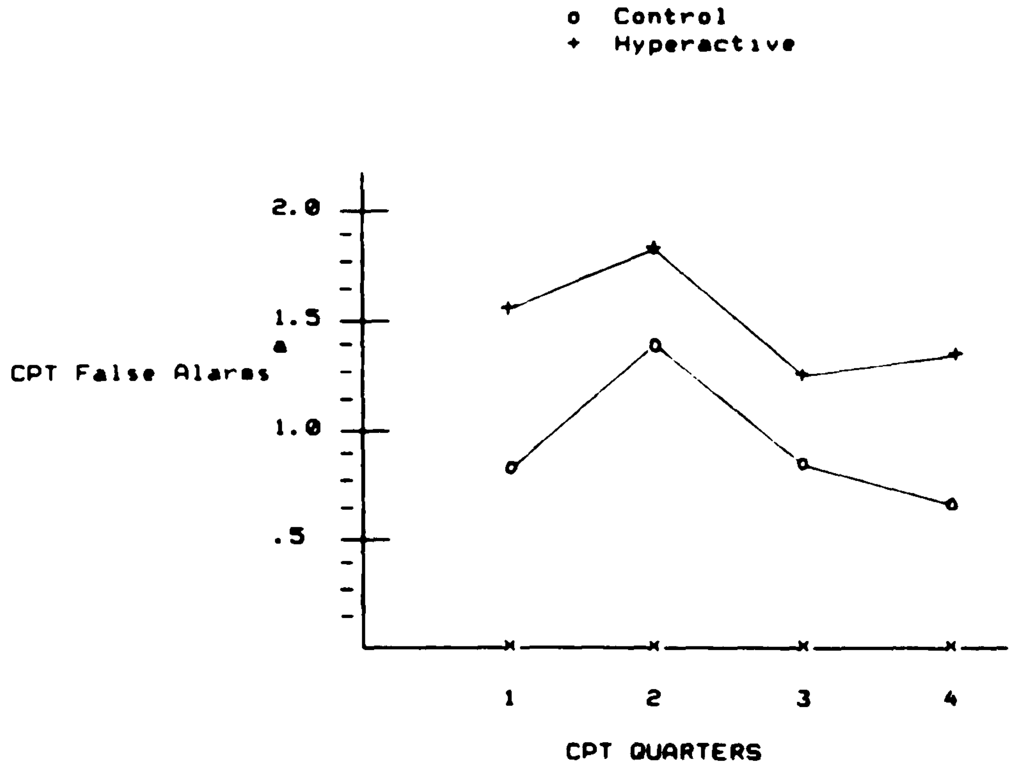
As a putative measure of behavioral control, false alarms were also expected to deteriorate over time in the hyperactive group. There was only a trend in support of increased FA over time for the entire sample. There were also no significant findings when analyzed separately for each group [$F(1,70)=.186$, $p>.10$], nor was there a Group X Time interaction [$F(1,3)=1.36$, $p>.10$].. Moreover, the changes in FA performance were not systematic with time, but fluctuated across all Quarters. The age adjusted means (SD) of hits, hit RT, RT variability and false alarms are found in Table 2, Appendix C.

Figure 5. CPT Hit Performance Over Time
(controlling for age)



a Time Main Effect; p<.001
b Group X Time Interaction; p<.04

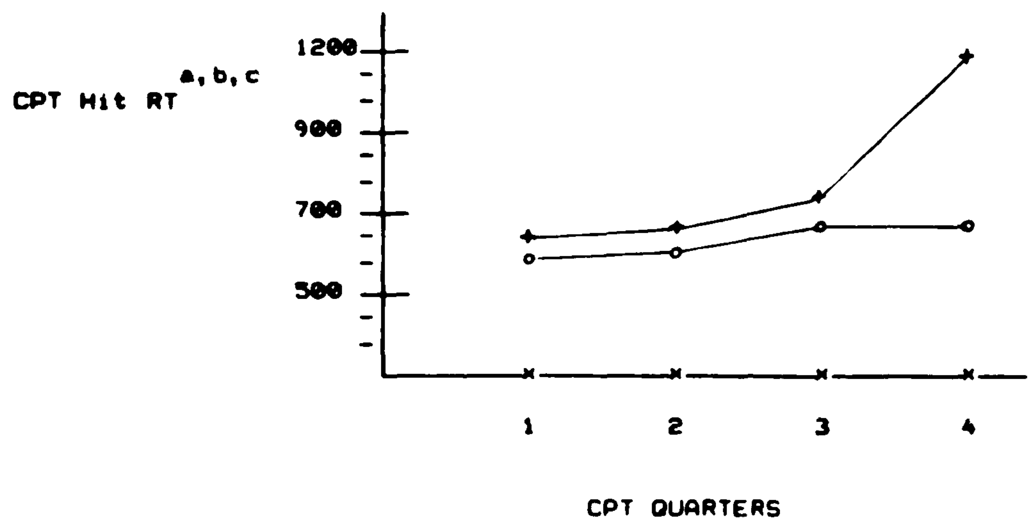
Figure 6. False Alarm Performance Over Time (controlling for age)



a NS Trend for Time; p<.08

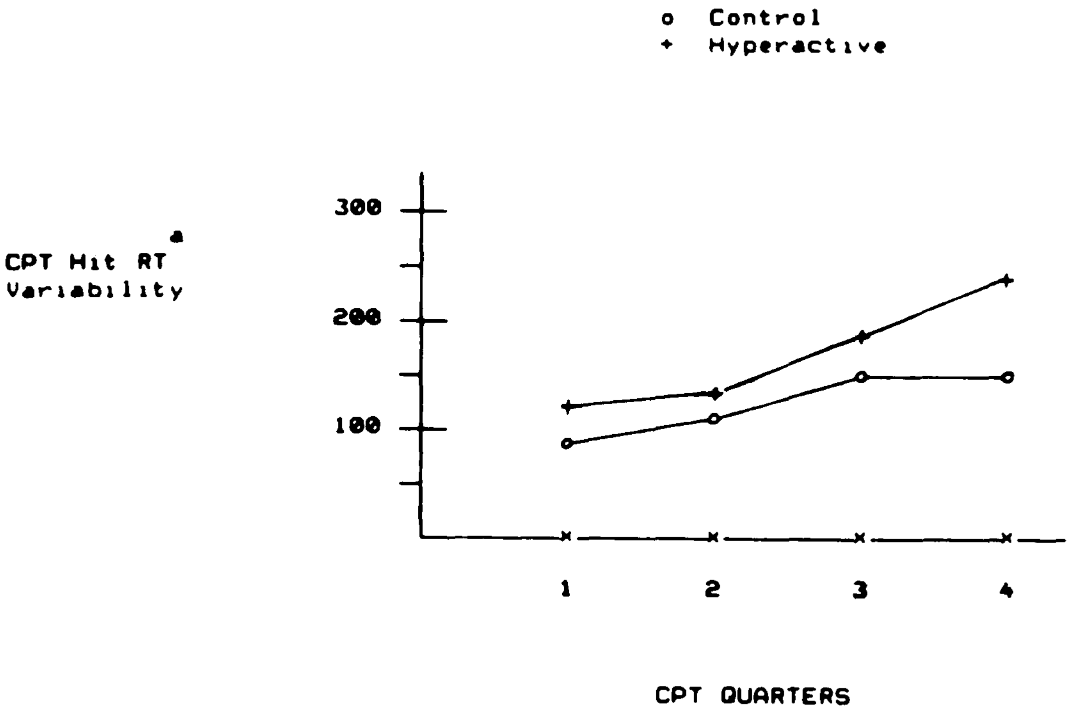
Figure 7. Hit RT Performance Over Time
(controlling for age)

o Control
+ Hyperactive



a Time Main effect; $p<.001$
b Group Main effect; $p<.04$
c Trend for Group X Time; $p<.06$

Figure 8. RT Variability Performance Over Time
(controlling for age)



a Time Main effect; $p < .001$

<u>Speed/Accuracy Relationships over Time</u>

SATOs were evaluated as negative correlations between errors and latency for hits. SATOs were examined in both hyperactive and nonhyperactive subjects for each of the four CPT time periods. The specific predictions were that the hyperactive group would <u>not</u> be able to trade speed for accuracy, as opposed to the control group. Based upon the previous analyses of performance changes over time, it was also expected that the relationship between errors and hit RT would change over time.

Partial correlations (controlling for age) were conducted between total errors (FA + misses) and mean hit RT for each Quarter. Figure 9 graphs those relationships, and Table 14 contains the correlation coefficients. In the control group, the direction of all correlations was negative, evidencing SATOs. Speed and accuracy were significantly correlated in Quarters 2 and 3. Thus, for the middle portion of the task, nonhyperactive subjects slowed down in order to turn in accurate performances.

The situation was reversed for the hyperactive group. Although the small sample size often precluded sufficient power for significant p values, the magnitude of the relationships was substantial. During Quarter 1, hyperactive subjects performed slowly in order to preserve accuracy (SATO). However, the direction of the relationship substantially reversed. During Quarters 2, 3, and 4, the hyperactive group showed substantial positive relationships between speed and accuracy. That is, they had high error rates even at slow speeds. By the fourth Quarter, this relationship was particularly striking.

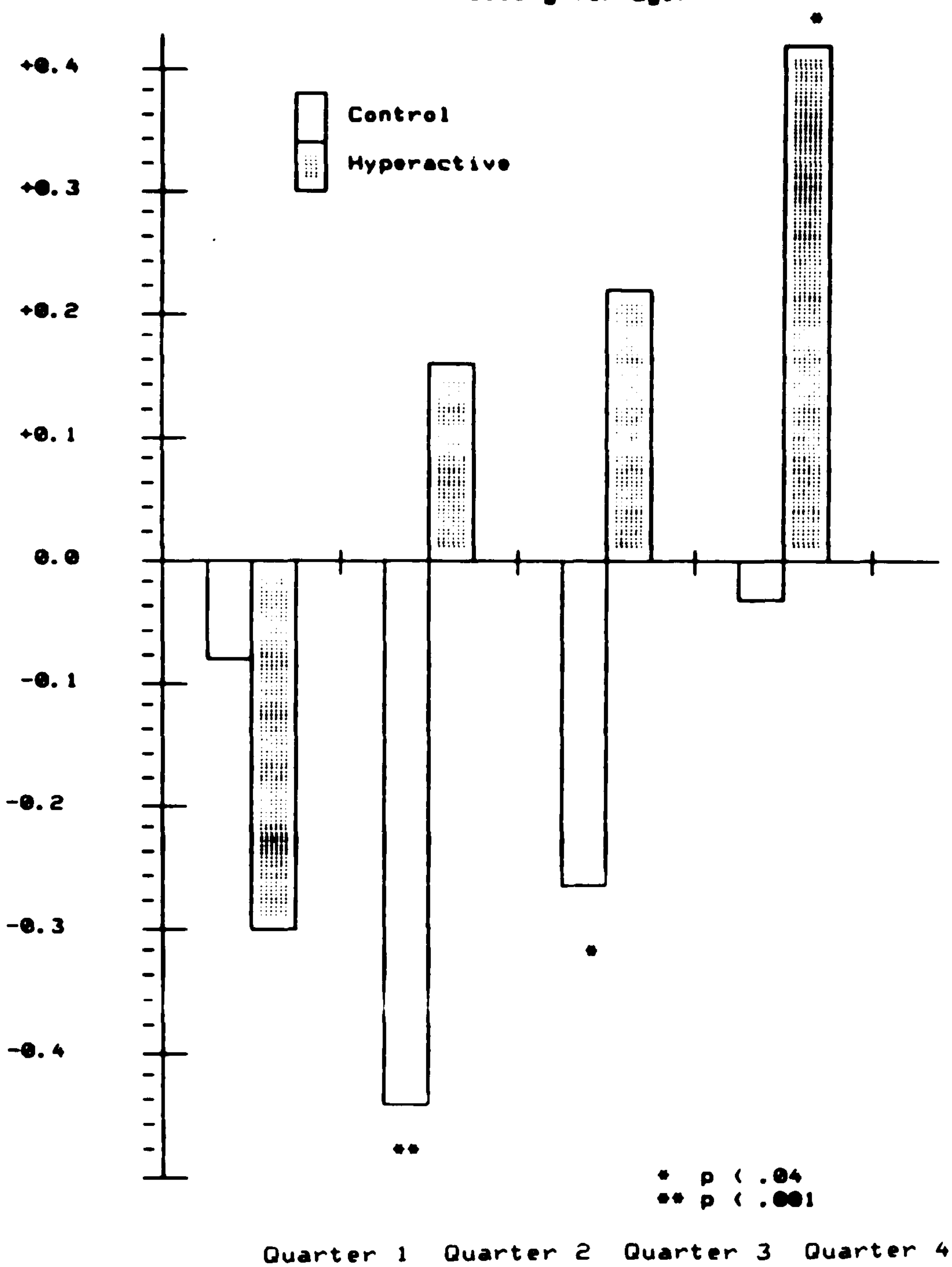
Table 14. Correlations Between Errors and Hit RT per Time Period

(controlling for age)

	Controls (n=50)	Hyperactives (n=22)
Quarter 1	-0.085 (p=.28)	-0.296 (p=.10)
Quarter 2	-0.450 (p=.001)	0.164 (p=.25)
Quarter 3	-0.273 (p=.03)	0.223 (p=.17)
Quarter 4	-0.032 (p=.40)	0.402 (p=.04)

****

Figure 9. Correlations Between Errors and Hit RT per Time Period (controlling for age)



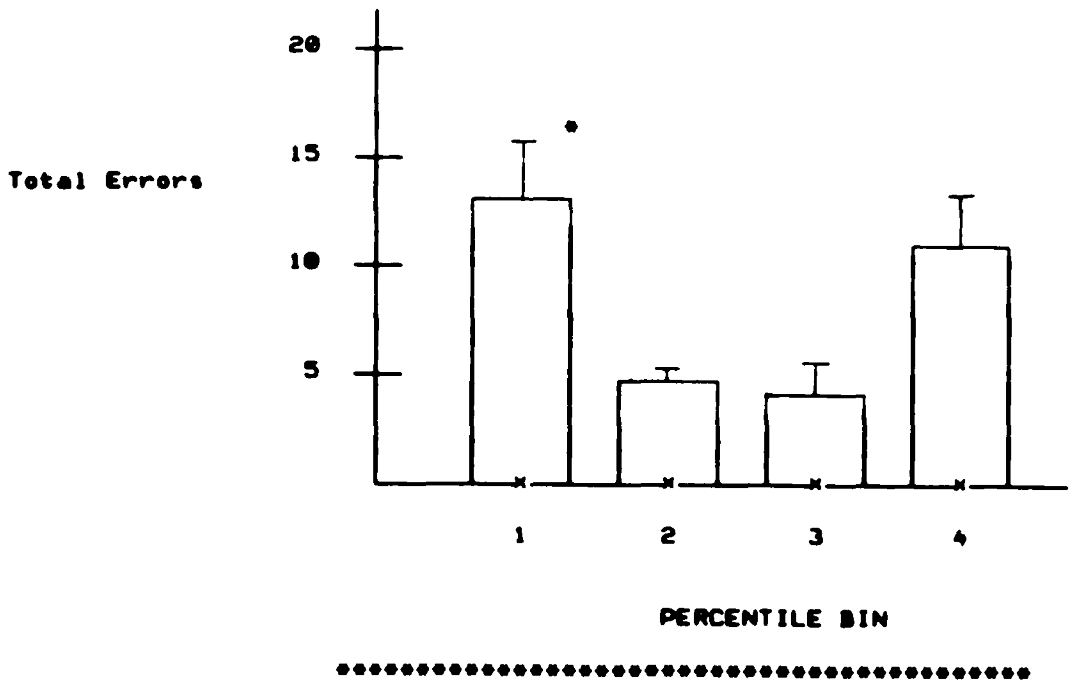
CPT Error Subtypes and Hit RT Relationships

Speed/accuracy relationships were examined in different classes of errors, in order to test the fast guess model. Total errors, FA, misses, Inattentive errors (misses + X-only FA), and Impulsive errors (A-not-X + A-only FA) were examined relative to hit RT. The specific predictions were that Impulsive errors would occur in subjects with fast average hit RTs, and Inattentive errors would occur in subjects with slow average RTs. Total errors were expected to occur at both RT extremes, as they are comprised of both FA and misses. In addition, hyperactive subjects were expected to demonstrate more Impulsive errors than nonhyperactive controls.

Subjects were divided into 4 groups ("Bins") by average hit RT, from fastest to slowest. Bin 1 (n=16) contained subjects with mean hit RTs below the 25th percentile (570 msec.). The children in Bin 2 (n=20) had mean hit RTs between the 25th and 50th percentiles (570-635 msec.). Bin 3 (n=18) contained subjects with hit RT between the 50th and 75th percentiles (636-715 msec.), and Bin 4 (n=19) contained subjects with mean hit RTs greater than the 75th percentile (716 msec.). Figures 10-14 graph error types per bin. The ordinate contains the dependent variables, and the abscissa is RT Bins 1-4. Table 3, Appendix C contains the age adjusted means (SD) for these variables for the entire sample (n=73).

Figure 10

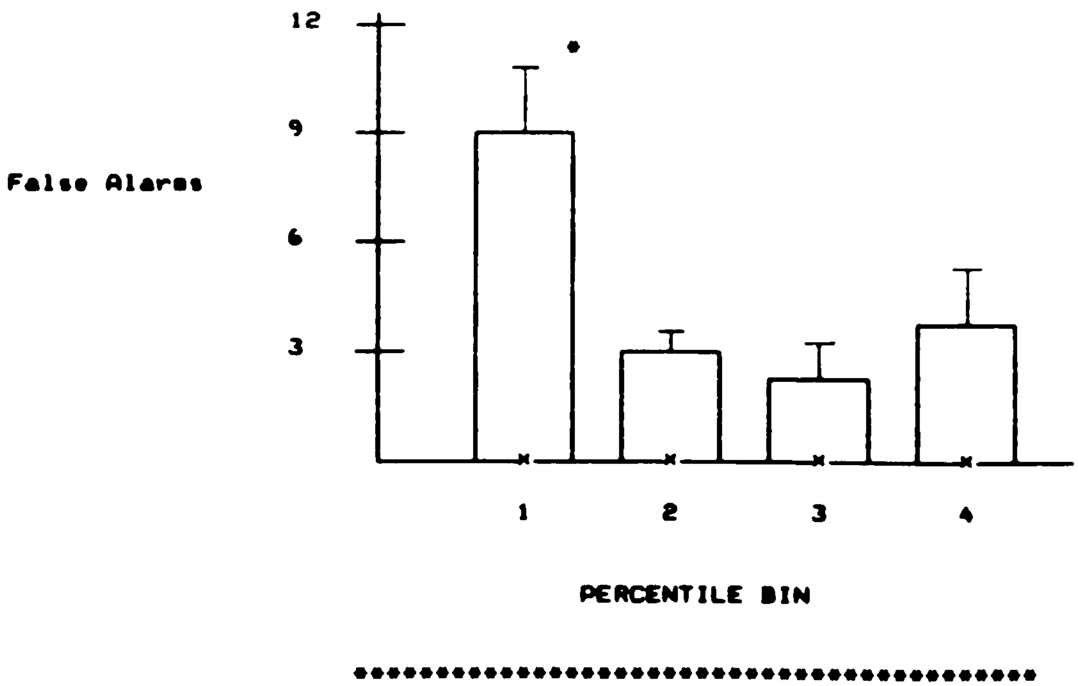
Mean (SEM) Total Errors per Reaction Time Quartile



* Bin 1 > Bins 2, 3; p<.05

Figure 11

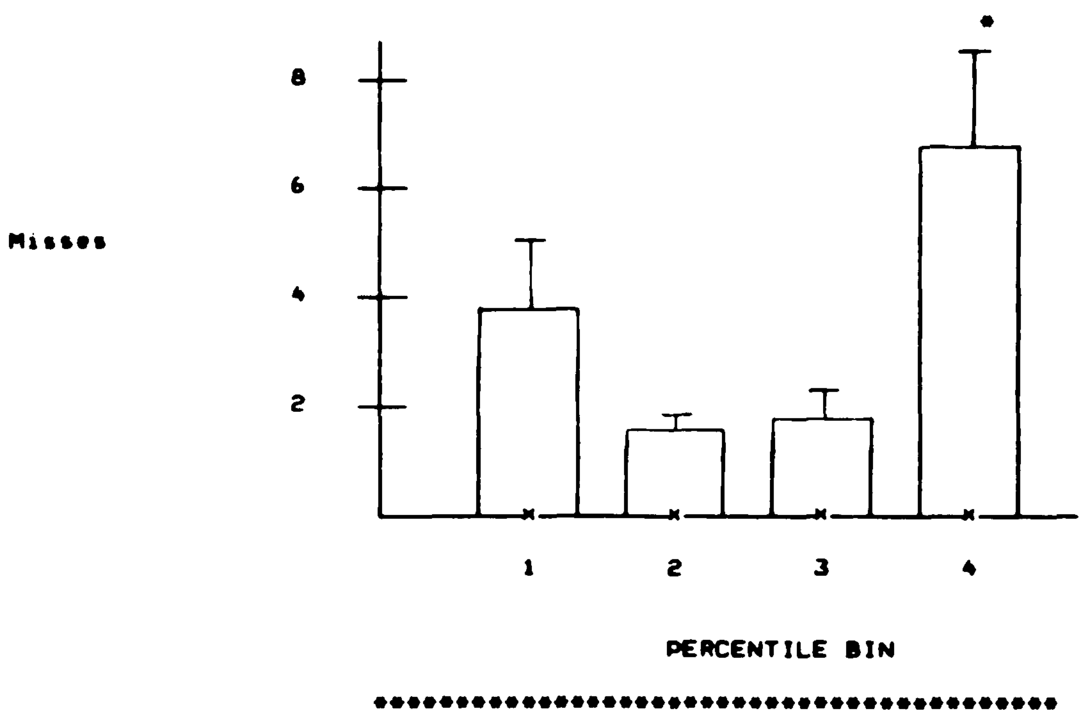
Mean (SEM) False Alarms per Reaction Time Quartile



Bin 1 > Bins 2, 3, 4; p<.05

Figure 12

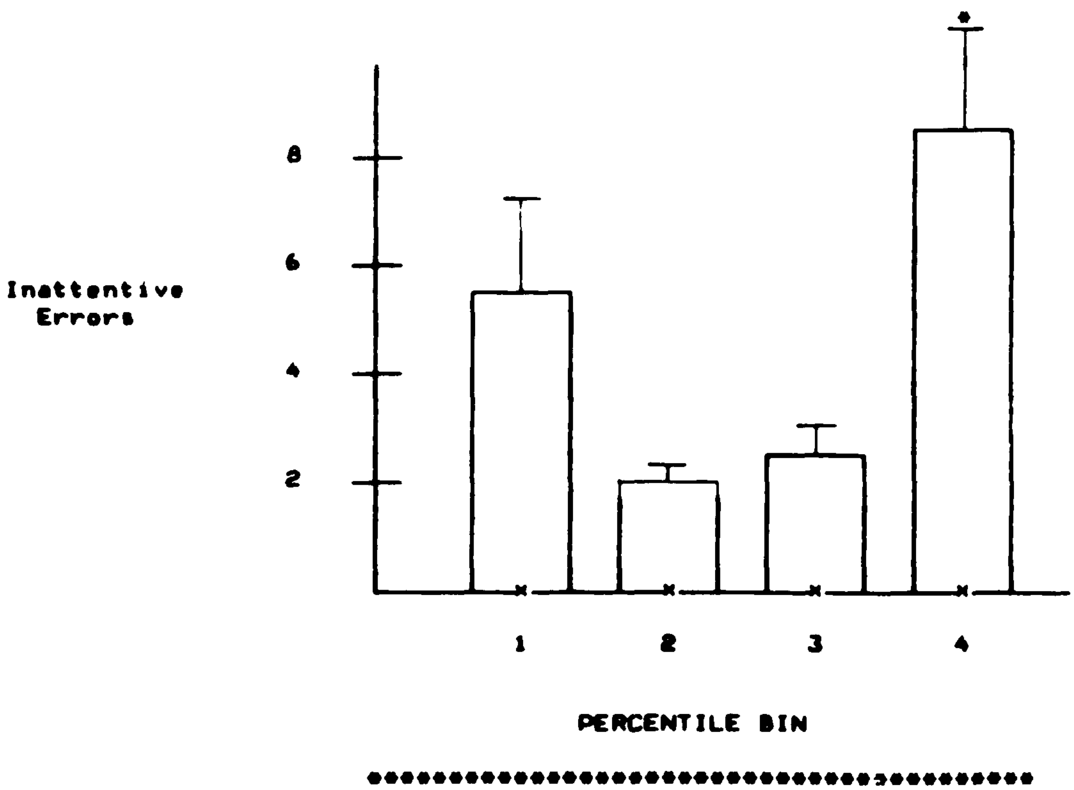
Mean (SEM) Misses per Reaction Time Quartile



Bin 4 > Bins 2, 3; p<.05

Figure 13

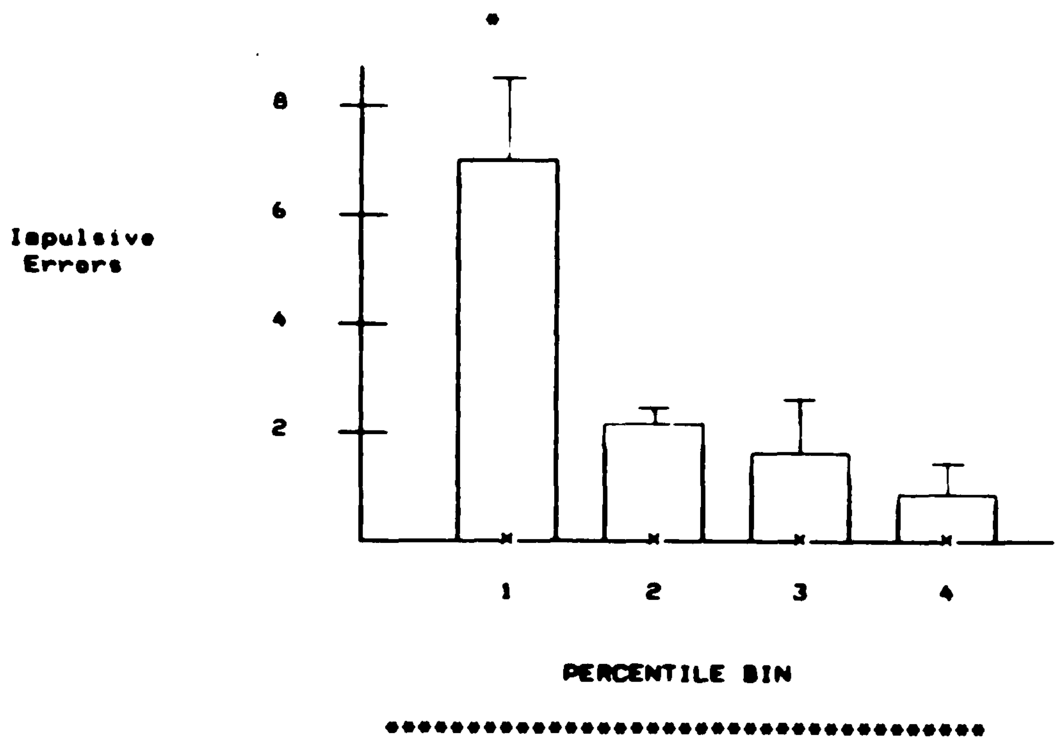
Mean (SEM) Inattentive Errors per Reaction Time Quartile



Bin 4 > Bins 2, 3; p<.05

Figure 14

Mean (SEM) Impulsive Errors per Reaction Time Quartile



Bin 1 > Bins 2, 3, 4; $p<.01$

As can be seen, different error types are strongly associated with different RTs. When the means were subjected to ANCOVAs (with age as the covariate), significant differences were seen for total errors [$F(3,72)=6.08$, $p<.001$], false alarms [$F(3,72)=5.72$, $p<.001$], misses [$F(3,72)=3.85$, $p<.01$], Inattentive Errors [$F(3,72)=4.60$, $p<.005$], and Impulsive errors [$F(3,72)=8.17$, $p<.001$].

There was a bimodal distribution for total errors, with increased errors in children with both very slow and very fast mean RTs. As total errors includes both false alarms and misses, a bimodal distribution was expected. Post hoc Scheffe testing, however, revealed that the most total errors were made by the fastest subjects [Total errors in Bin 1 > Bins 2, 3, $p<.05$].

When false alarms alone were graphed, the distribution was unimodal, with significantly more false alarms occurring in children with the fastest average hit RTs (Bin 1 > Bins 2, 3, 4, $p<.05$). Although the distribution of <u>misses</u> was also bimodal, significantly more misses were made by the slowest children (Bin 4 > Bins 2, 3, $p<.05$).

Since false alarms (which are generally thought to be impulsive in nature) and misses (which are considered inattentive errors) had different distributions at different RTs, they were grouped into Inattentive and

Impulsive error types. Inattentive errors followed a bimodal distribution, with errors occurring predominantly at the RT extremes. However, post hoc testing revealed significant differences in error rate only at the slowest RTs. Children with the slower mean RTs made more Inattentive errors than children at the two intermediate RT averages (Bin 4 > Bins 2, 3, $p<.05$). The situation was reversed for Impulsive errors, where the highest error rates were seen in children with the fastest RTs (Bin 1 > Bins 2, 3, 4, $p<.01$).

These error types were also analyzed in the two groups in order to examine differences between hyperactive and nonhyperactive children. Two-way (Group X Bin) ANCOVAs with age as the covariate were performed. There were no significant group differences across bins for total errors [$F(1,71)=.142$, $p>.10$], false alarms [$F(1,71)=.666$, $p>.10$], misses [$F(1,71)=.08$, $p>.10$], Inattentive errors [$F(1,71)=.53$, $p>.10$], or Impulsive errors [$F(1,71)=.36$, $p>.10$]. Table 16 contains the age-adjusted means (SD) for these variables by groups.

Table 16. Age Adjusted Mean (SD) of CPT Error Types for Hit Reaction Time Quartiles by Group

	Control (n=50)	Hyperactive (n=22)
Total Errors[a]		
Bin 1	12.65 (11.51)	13.43 (9.67)
Bin 2	4.33 (2.31)	5.11 (3.54)
Bin 3	3.85 (7.32)	4.63 (0.55)
Bin 4	10.33 (9.69)	11.11 (11.1)
False Alarms[a]		
Bin 1	8.62 (7.44)	9.77 (6.95)
Bin 2	2.49 (1.36)	3.64 (2.12)
Bin 3	1.86 (5.11)	3.01 (1.10)
Bin 4	3.27 (3.92)	4.42 (8.82)
Misses[b]		
Bin 1	4.03 (5.31)	3.66 (5.37)
Bin 2	1.83 (1.50)	1.47 (1.41)
Bin 3	1.98 (2.76)	1.61 (0.89)
Bin 4	7.06 (9.28)	6.69 (6.26)
Inattentive Errors[b]		
Bin 1	5.06 (5.24)	6.15 (10.14)
Bin 2	2.05 (1.6)	3.14 (0.71)
Bin 3	2.13 (2.84)	3.22 (1.23)
Bin 4	7.89 (8.86)	8.98 (7.83)
Impulsive Errors[c]		
Bin 1	7.17 (7.09)	6.58 (3.11)
Bin 2	1.98 (1.23)	1.39 (1.41)
Bin 3	1.75 (5.0)	1.16 (0.89)
Bin 4	1.20 (2.37)	0.61 (2.77)

****

a Main effect for Bin; $p<.002$
b Main effect for Bin; $p<.02$
c Main effect for Bin; $p<.001$

Discussion

These data suggest that several CPT variables may be meaningful measures of sustained attention, supporting many of the initial predictions regarding the vigilance performance of children. While mean values for all CPT measures failed to differentiate the groups, analyses of these measures over time revealed differences in performance.

There were significant and systematic changes over time for all CPT measures except false alarms. When taken as a whole, subjects made fewer hits, at slower and more variable RTS with increased task duration. Changes in false alarm performance were not systematic over time.

Examination of Group effects and interactions for hits, hit RT, and RT variability, however, revealed that the vigilance decrement was group specific. The hyperactives were indeed slower and less accurate over time, but the nonhyperactive subjects did not show these changes. Both groups became more variable in hit RT over time.

It is interesting to note that in this analysis, when controlling for age, the hyperactives actually began the test making more hits than their nonhyperactive peers, although this quickly dropped off with time. Similarly, hit RT was even between the groups until the last Quarter, when that of the hyperactives rose sharply. The equivalence of hyperactive and nonhyperactive subjects at certain points in the task suggests that the use of average, overall values may obscure meaningful differences. Perhaps this accounts for some of the confusion in the literature as to the presence or absence of sustained attention deficits. These data suggest that it is not the average performance during the CPT as a whole, but decrements in both speed and accuracy performance over time which is the more valid and sensitive measure of sustained attention in hyperactives.

It was expected that hyperactives performance would decline markedly relative to controls, as was the case. However, it was also expected that nonhyperactive subjects would show a "sustained attention" decrement in RT performance over time. This was not the case, as the Group effect and the strong interaction trend for Group X Time demonstrate. Only hyperactives RTs became slower over time, suggesting that their performance decrements may result from systematic changes over the duration of the task, rather than from fluctuating levels within the task.

More importantly, it appears that a combination of decreased hits and slowed RTs characterizes this decrement. The significant Group X Time interaction for hits suggests that in hyperactives, but not nonhyperactive controls, the speed decrement is accompanied by a decrease in accuracy. Nonhyperactive subjects do not demonstrate a decrease in accuracy over time. It may be that the sustained attention deficit in hyperactives is reflected in their inability to make changes in their performance strategy to accommodate the effect of fatigue as the task progresses.

In order to explore this possibility, the relationships between speed and accuracy over time were evaluated. Speed and accuracy are typically treated as related performance measures when investigating strategy effects. According to Sergeant and Scholten (1985), negative correlations between speed and errors index SATOs. Moreover, hyperactive children are thought to make fast responses at the expense of accuracy, which presumably underlies their poor performance.

The present study however, does not support this contention. Only nonhyperactive subjects showed the negative association between errors (false alarms + misses) and speed (hit RT). This was significant only during the middle portion of the task. Perhaps nonhyperactive children can adjust their performance strategies until they fatigue during the late stages of the task.

The situation was reversed for the hyperactive subjects, who were only able to adjust their strategies during the first Quarter of the CPT. Thereafter, their performances were characterized by losses in both speed and accuracy, as the positive relationship between hit RT and error reflects. This was particularly striking by the last Quarter.

These findings further support the notion that, for hyperactives, sustained attention decrements may result from strategy deficits over time. Hyperactives lose both speed <u>and</u> accuracy as the task progresses, whereas nonhyperactives sacrifice speed alone. Thus for hyperactives, speed and accuracy may be separable, albeit related, processes, while in nonhyperactive controls they remain functions of strategy tradeoffs.

Thus there was evidence for different relationships between speed and errors in hyperactives, as compared to controls. Those findings, plus unexpected results for false alarms over time suggested that error-prone performance, particularly in hyperactive children, might not conform to the traditional SATO model. False alarms (which are typically used as an index of performance, and which were expected to change over time) did not increase monotonically, but fluctuated nonsystematically across the Quarters in both groups. The data weakly suggest that FA rate might change in some way with task duration, but the nature of this change is unclear from these analyses. Perhaps false alarms do not share the same speed/accuracy system as RT and hits.

One problem with the correlational analyses above was that the error measure contained both false alarms and misses (which are the converse of hits). It was of interest to explore the relationships between speed and accuracy as reflected by false alarms and misses, together and separately.

This was done for various error subtypes by testing the fast-guess model (Yellot, 1971). Essentially a variation of the SATO model, it predicts that high error rates are associated with fast RTs, and that low error rates result from slow performance. Sergeant and Scholten (1985) were unable to show that this model predicts the performance of hyperactive subjects, although it predicted the performance of nonhyperactives. Their analysis was not specific as to error classes.

The present analyses grouped errors by types; total errors (false alarms + misses), false alarms, misses, Inattentive errors (misses + X-only false alarms), and Impulsive errors (A-not-X + A-only false alarms). Subjects were grouped according to average hit RT, from subjects with the fastest RTs (Bin 1) to subjects with the slowest average RTs (Bin 4). Interpretation of the fast-guess model within this framework predicts that Impulsive and Inattentive errors will be associated with fast and slow hit RTs, respectively. Thus Impulsive errors would occur predominantly in children in Bin 1, and Inattentive errors would occur in the Bin 4 children predominantly.

The data strongly supported those predictions. False alarm errors were made predominantly by children with the fastest average hit RTs, and misses by the children with the slowest RTs. This supports the fast-guess model. Similarly, Impulsive errors were chiefly associated with the fastest RTs, while Inattentive errors were made by children with the slowest RT performances. These results were quite striking evidence that on the whole, the fast-guess model predicts the association between error-prone responding and speed.

There were further predictions about the performance of the two groups which these analyses did not support. If the fast-guess model predicts the performance of the hyperactive group, there should be Group X Bin differences for Impulsive errors and false alarms. This was not found. There are two possibilities which might explain the lack of significant findings. First, the number of hyperactive subjects per Bin was quite low. Thus, there might not have been sufficient power to yield significant results.

The other possibility supports Sergeant and Scholten (1985), who were also unable to show that the fast-guess model predicted the performance of their hyperactive sample. We have evidence from the attentional performance over time and from the correlations over time to suggest that hyperactives do not exhibit the traditional SATO function. Thus the assumptions from that model that hyperactives are expected to make predominantly fast, impulsive errors may be unwarranted. The SATO model may be valid only to the extent that the child is capable of altering his/her strategy in accordance with the task demands. Consistent with other findings (Sergeant & Scholten, 1985), hyperactives do not seem to be able to make these adjustments.

In sum, the CPT vigilance performance of hyperactives is characterized by decrements in accuracy and (perhaps) speed over time. In addition, they do not show the same relationship between lowered speed and maintained accuracy as their nonhyperactive peers. Nonhyperactive children appear capable of slowing down in order to preserve accuracy until the last portion of the lengthy and tiring task, while hyperactives could only sustain this function during the first part of the task. This suggests that the "sustained attention deficit" of hyperactives reflects difficulties in adjusting and modulating performance strategy over time.

GENERAL DISCUSSION

Two experiments were conducted to test hypotheses about attentional processes in children. One study examined the separation of attentional processes and their relationship to behavior problems in non-referred school children. The second examined sustained attention in attention/behavior disordered and normal children.

Experiment 1 suggests that vigilance and attentional performance are separable into independent dimensions, including a speed/consistency (sustained effort/attention) factor and an accuracy (behavioral control) factor. Relative to controls, hyperactives demonstrated poor behavioral control, but not poor sustained effort. Moreover, the relationships between these factors and teacher ratings provided further evidence that the behavioral control factor, but not the sustained attention factor, was related to problems of behavior in the classroom.

These data are similar to those derived from a factor analysis of attentional test measures in adults (Mirsky, 1989), which also aimed to evaluate the attentional components measured by various commonly used tests. That study also yielded a four factor solution, including focus, sustain, encode, and shift factors. Many of the tasks were analogous to the tests used in the present study, including

CPT hits, false alarms, reaction time and RT variability, letter cancellation and digit span.

The sustained attention factors in both studies are analogous. However, in the current study, CPT measures are separable, while in Mirsky's study all CPT measures loaded a single sustained attention factor (Mirsky, 1989). This may be due to the fact that adults rarely make errors of commission on the CPT. Thus the issue of a separate behavioral control dimension involving false alarms may be important only in children. This hypothesis should be investigated more thoroughly so that it might be incorporated into a model for CPT performance in children.

Experiment 2 addressed the relationships between speed and accuracy in hyperactive and nonhyperactive children. Performance over time and speed/accuracy tradeoffs were the particular areas of concern. The analyses showed that the CPT performances of all subjects were less accurate, slower and more variable with time. This time effect was due, however, to the performance of the hyperactive subjects in the sample. Their performance was characterized by losses of both speed and accuracy over time. Nonhyperactive controls did not show this decline. This challenges the traditional SATO model of increased error rates associated with fast performance, at least as far as the performance of the hyperactives group is concerned.

The analysis of the pattern of relationships between errors and RT over time validates the contention that hyperactives show different relationships between speed and accuracy than nonhyperactives. There are a few possibilities which could account for this. First, the processes may be somewhat independent, and their simultaneous decrement over time may be a coincidental effect of generalized fatigue. The second possibility is that the task requires adjustments in strategy to resist the effects of fatigue. Hyperactives may be unable to make the necessary adjustments to preserve performance over time. Thus, their entire performance suffers as they attempt to meet increased task demands in the face of fatigue.

There was no evidence to support the notion that the hyperactives are more impulsive than the nonhyperactive controls. While the SATO and fast-guess models predicted the relationships between errors (particularly Impulsive errors and false alarms) and speed for the entire sample, there were no group differences for any of the error types.

This result is not surprising given the proposal that hyperactives and controls differ in the use of the SATO. Thus high error rate may not be associated with RT in hyperactives, but rather be related to response control. This goes back to the original distinction between behavioral control and sustained effort. The performance deficit of hyperactive children over time cannot thus be accounted for by impulsivity alone.

If hyperactives are not more impulsive than nonhyperactives, and if they do not become more impulsive with time, what process(es) underlay their CPT deficits? Perhaps the difficulty lies in increasing loss of behavioral control over responding with time on task. It is the relationship between output (speed/consistency) and control (accuracy) which determines, in part, the quality of vigilance performance. Hyperactive children do not appear to be able to adjust or modulate this relationship over time. Without use of appropriate and efficient accommodations to resist fatigue, the hyperactive child finds the performance goals of "fast" and "accurate" to be out of reach. The nonhyperactive child, however, is able to reconcile these goals with the SATO.

There are attentional models which provide a framework within which to interpret the vigilance performance of hyperactives. Capacity models presume variable limits on energy available for cognitive work (Hasher & Zacks, 1979; Kahneman, 1973). These energy pools may be flexibly allocated according to motivation, goals, and task demands. State variables such as arousal and mood may affect this allocation (Hasher & Zacks, 1979). As resource allocation changes, the quality of cognitive operations may also change. Thus, diminished allocation of energy does not simply reduce quantity of output, but may change it in other fundamental ways (Sanders, 1983).

It is possible to integrate the present data with the notion of resource allocation through the feedback, or systems model. This model posits central evaluator mechanisms which serve to compare input (perception) and output (behavior) with regard to some external reference value (Carver & Scheier, 1982; von Bertalanffy, 1968). Information about discrepancies between the present state of the organism and that value lead to adjustments of behavior upon the environment. The evaluator coordinates arousal and activation by providing the organism with information about the quality of performance, adherence to preset goals, and energy available for continued work (Sanders, 1983).

In this model, the action of the evaluator is upon the allocation of effort. Effort then feeds to arousal and activation, which feed back to the evaluator. This entire system thus operates with continual feedback onto processing stages central to standard detection and response choice activities (Sanders, 1983). Recall that the area(s) of modulation of arousal levels, evaluating ongoing performance, and adjusting performance commensurate with situational demands are precisely the areas in which hyperactives experience the most difficulty (Douglas, 1983). These difficulties are most pronounced in situations which require active, reflective, and sustained effort.

The present data may be interpreted within this model. The findings suggest that hyperactive children have fundamental difficulties with areas of attentional performance which include performance speed and performance accuracy. Specifically, they appear to have difficulty maintaining fast, accurate responding through the duration of tasks such as the CPT although their performance during certain portions of the task is normal. The fact that they are capable of good areas of performance argues against a global defect, and argues more strongly for subtle, sustained and strategic difficulties which affect task efficiency. Perhaps hyperactive children have problems in the fine-tuning of the evaluator mechanisms which would ordinarily permit them to appraise and adjust their behavior.

This formulation fleshes out the SATO models, which do not ordinarily posit mechanisms which regulate the statistical relationships between speed and accuracy. If effort and energy are presumed to be limited in quantity, it might be expected that all children would be vulnerable to performance deficits over time. The inefficient use of allocation strategies might tax this system in hyperactives. Nonhyperactive children, on the other hand, are able to appraise, adjust and conserve energy such that they are ensured adequate performance over time.

This is only one of many possible vignettes in which failures to monitor ongoing levels of arousal and action could explain the behavioral and attentional difficulties of hyperactives. Central to these arguments is the notion that the "core symptoms" of ADHD are heterogeneous in nature, variably assessed, and highly subjective. Furthermore, the nature of the symptom is clearly a function of its measurement. Thus the definition of singular cognitive, attentional, and behavioral deficits and the hunt for the definitive symptom cluster might be misdirected. Perhaps the overt, clinical symptoms of ADHD such as inattention, impulsivity, and overactivity are phenotypic manifestations of a more central regulatory deficit.

Further studies are needed to demonstrate the presence of a behavioral control factor, and document differences between children and adults, and between children with attention/behavior disorders and normal children. Developmental changes in attention and behavioral control, and clinical evidence of changes in behavioral control with successful stimulant medication in hyperactives are also important to document. Finally, correlations between test performance, behavioral control and electrophysiological state over time is necessary, in order to establish connections between arousal, activation and performance.

There are numerous conceptual and methodological issues which still remain. Regarding attention as a subprocess within a hierarchy of function, and as a process with subcomponents of its own may help to reduce the frustration and confusion which has resulted, in part, from attempts to pinpoint a single deficit of attention in hyperactives. More importantly, just as we do not interpret other child behavior and cognition according to adult standards, we need attentional models which are sensitive to the differences between adults and children.

The present work has shown that the attentional performance of children does not conform to several classical models. The failure of many studies to demonstrate consistent attentional deficits in hyperactive children may be due to a conceptualization of attention (particularly vigilance) which was developed to predict the behavior of adults, reliance on instruments which were developed to test these inappropriate models, and the basic heterogeneity of the study population. The development of an age-appropriate framework in which to interpret vigilance might clarify some of these issues. Studies are needed which focus on the function and development of central regulatory mechanisms which could modulate attention. This might prove to be more fruitful than expecting the performance of hyperactive children to conform to adult models of attention. Clearly, the nature of this mechanism and its possible operation in children needs further delineation, and the development of child models of attention has a long way to go.

APPENDIX A. Results of Pilot Experiments

Table 1. Pilot Experiment 1--Sample Characteristics

n=62

Age (yrs)	
Mean	9.26
SD	1.93
Range	5.75 - 13.75
Gender	
Boys	53
Girls	9
WISC-R Full Scale IQ	
Mean	94.98
SD	11.28
Range	80.0 - 129.0
Status	
Inpatient	38
Outpatient	24

Table 2. Pilot Experiment 1

Varimax Rotated Factor Matrix for Attentional and Cognitive Measures

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Cancellation error	0.021	0.981*	0.186	0.177
Cancellation time	-0.040	-0.141	-0.130	-0.635*
CPT-FA	-0.883*	-0.080	-0.350	0.127
CPT-%Hits	0.546*	-0.073	-0.290	0.134
CPT-RT Hits	0.090	0.021	0.789*	0.080
CPT-RT Variability	-0.101	0.199	0.506*	0.382
WISC-R Freed. from Dist.	0.383	-0.380	0.159	0.107
WISC-R Verbal	0.130	-0.022	0.187	0.176
WISC-R Perceptual Org.	0.016	-0.245	0.044	0.640*

* Factor loadings > 0.50

Table 3. Pilot Experiment 2

Sample Characteristics on Diagnostic Groups

Variable	ADD	CD	Mixed
Age			
Mean	8.73	9.03	8.82
SD	1.28	2.23	1.75
Full Scale IQ			
Mean	92.29	101.38	93.22
SD	9.43	10.99	10.68

Table 4. Pilot Experiment 2

Factor Scores by Diagnostic Group

	ADD	CD	Mixed
	Mean (SD)	Mean (SD)	Mean (SD)
Factor 1[a]	450.18 (128.6)	561.52 (64.9)	486.67 (103.32)
Factor 2[b]	570.93 (109.04)	467.17 (71.42)	504.09 (106.02)
Factor 3[b]	545.65 (77.95)	495.19 (79.68)	483.95 (121.54)
Factor 4[b]	513.10 (52.51)	494.57 (93.32)	502.13 (78.10)

a $p < 0.06$
b $p > 0.10$

****

Factor 1 = Behavioral Control
High scores are good

Factor 2 = ?Visual Attention
Low scores are good

Factor 3 = Speed/Consistency (sustained attention)
Low scores are good

Factor 4 = Perceptual organization
High scores are good

APPENDIX B

Tests and Forms Used

A) The Revised Conners Teacher Questionnaire (Goyette, et al., 1978)

1. Restless in the "squirmy" sense.
2. Makes inappropriate noises when he shouldn't.
3. Demands must be met immediately.
4. Acts "smart" (impudent or sassy).
5. Temper outbursts and unpredictable behavior.
6. Overly sensitive to criticism.
7. Distractibility or attention span a problem.

8. Disturbs other children.
9. Daydreams.
10. Pouts and sulks.
11. Mood changes quickly and drastically.
12. Quarrelsome.
13. Submissive attitude toward authority.
14. Restless, always "up and on the go".

15. Excitable, impulsive.
16. Excessive demands for teacher's attention.
17. Appears to be unaccepted by the group.
18. Appears to be easily led by other children.
19. No sense of fair play.
20. Appears to lack leadership.
21. Fails to finish things that he starts.

22. Childish and immature.
23. Denies mistakes or blames others.
24. Does not get along well with other children.
25. Uncooperative with classmates.
26. Easily frustrated in efforts.
27. Uncooperative with teacher.
28. Difficulty in learning.

<u>Conduct Problems Factor</u>: 4, 5, 6, 10, 11, 12, 23, and 27.
<u>Hyperactivity Factor</u>: 1, 2, 3, 8, 14, 15, and 16.
<u>Inattention/Passivity Factor</u>: 7, 9, 18, 20, 21, 22, 26, and 28.

B) Sample Stimuli & Score Sheet for Target Detection Test

ID#________________ Date Tested________________

Name __________________ Date of Birth ____________

Age __________

Form	Time (sec.)	Score
10/75-X	20	______
10/75-5	20	______
15/150-X	30	______
15/150-5	30	______
LIF	30	______
592	30	______

Total Score ______

X

S M R E U P D

S D R R I R F O

A H K X P L T

Q R T E H O

A M X E H T S

S D V V U

P E R I X K P R L

D W P R X E T

R F M T F U E P

E T K S X P K Y W

X R E R Y

C Y Q K D X L

E D S W B F R X

R U G M X K G S

X N P F M N

P D E S S X G V

S Y P X O D Q

Y X S H K L P X

Z K S D E R

X G J P C E D

D D W K H S T

C) Matching Familiar Figures Test (Kagan, 1964)
Formula for Impulsivity/Reflectivity Score
(Salkind & Wright, 1977)

MFFIMP = z (ERROR PERCENT) - z (LATENCY PERCENT)

Large positive score= Impulsive
Large negative score= Reflective

APPENDIX C

Additional Tables from Experiment 2

Table 1. Age Adjusted Means (SD) of CPT Variables per Time Period

(n=72)

Hits[a]		
	Quarter 1	9.43 (1.29)
	Quarter 2	8.99 (1.56)
	Quarter 3	8.77 (1.88)
	Quarter 4	8.66 (1.71)
Hit Reaction Time[b]		
	Quarter 1	601.891 (94.80)
	Quarter 2	628.79 (108.36)
	Quarter 3	702.75 (129.81)
	Quarter 4	927.10 (166.39)
Reaction Time Variability[c]		
	Quarter 1	104.24 (66.72)
	Quarter 2	124.90 (72.30)
	Quarter 3	169.56 (97.01)
	Quarter 4	194.43 (108.58)
False Alarms[d]		
	Quarter 1	1.16 (1.87)
	Quarter 2	1.58 (2.68)
	Quarter 3	1.00 (1.66)
	Quarter 4	0.97 (1.14)

****

a Time effect; $F(3,209)=10.49$, $p<.001$
b Time effect; $F(3,209)=4.5$, $p<.005$
c Time effect; $F(3,209)=11.51$, $p<.001$
d Trend for Time; $F(3,209)=2.3$, $p<.08$

Table 2. Age Adjusted Mean (SD) on CPT Variables per Time Period by Group

	Controls (n=50)	Hyperactives (n=22)
Hits[a,c]		
Quarter 1	9.09 (1.4)	9.77 (1.06)
Quarter 2	8.89 (1.55)	9.08 (1.6)
Quarter 3	8.87 (1.78)	8.68 (2.04)
Quarter 4	8.55 (1.67)	8.77 (1.82)
Hit Reaction Time[a,b,d]		
Quarter 1	568.54 (96.65)	635.25(82.84)
Quarter 2	595.16 (16)	662.43 (121.49)
Quarter 3	662.08 (111.32)	743.43 (160.07)
Quarter 4	669.22 (150.35)	1184.97 (192.5)
Reaction Time Variability[a]		
Quarter 1	89.70 (74.86)	118.77 (45.46)
Quarter 2	112.48 (73.30)	137.31 (72.27)
Quarter 3	148.94 (95.62)	190.18 (90.96)
Quarter 4	148.32 (104.84)	240.54 (115.76)
False Alarms		
Quarter 1	0.79 (1.15)	1.54 (2.77)
Quarter 2	1.35 (2.05)	1.81 (3.84)
Quarter 3	0.79 (1.74)	1.22 (1.48)
Quarter 4	0.63 (0.90)	1.31 (1.49)

****

a Main effect for Time Period, $p<.001$
b Main effect for Group, $p<.04$
c Group X Time Interaction, $p<.04$
d Trend for Group X Time, $p<.06$

Table 3. Age Adjusted Mean (SD) of CPT Error Types for Hit Reaction Time Quartiles *

(n=73)

Total Errors[a]	
Bin 1	12.92 (10.77)
Bin 2	4.67 (2.73)
Bin 2	4.06 (6.25)
Bin 4	10.88 (10.19)
False Alarms[b]	
Bin 1	9.03 (7.16)
Bin 2	2.97 (2.19)
Bin 3	2.18 (4.38)
Bin 4	3.80 (6.86)
Misses[c]	
Bin 1	3.84 (5.16)
Bin 2	1.64 (1.43)
Bin 3	1.82 (2.39)
Bin 4	6.83 (7.63)
Inattentive Errors[c]	
Bin 1	5.40 (7.13)
Bin 2	2.10 (1.48)
Bin 3	2.42 (2.48)
Bin 4	8.47 (8.10)
Impulsive Errors[d]	
Bin 1	7.01 (6.06)
Bin 2	2.15 (1.62)
Bin 3	1.59 (4.30)
Bin 4	0.85 (2.57)

****

a Bin 1 > Bins 2, 3; $p < .05$
b Bin 1 > Bins 2, 3, 4; $p < .05$
c Bin 4 > Bins 2, 3; $p < .05$
d Bin 1 > Bins 2, 3, 4; $p < .01$

* Bin 1 = 1st Quartile of Mean Hit RTs (n=16)
Bin 2 = 2nd Quartile of Mean Hit RTs (n=20)
Bin 3 = 3rd Quartile of Mean Hit RTs (n=18)
Bin 4 = 4th Quartile of Mean Hit RTs (n=19)

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