Understanding Physical Overactivity in ADHD: Utilization behavior

by

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B.Sc. University of Victoria, 1995
M.Sc. University of Victoria, 1997

A Dissertation Submitted in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Psychology

We accept this dissertation as conforming
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Abstract

The primary purpose of this study was to provide a better understanding of the typology and etiology of physical overactivity (hyperactivity) in ADHD. ADHD is uniquely characterized by inappropriate/excessive motor activity, yet motoric aspects of ADHD have been neglected in the research literature. Given high levels of intrusive/ inappropriate motor behaviors and evidence that the neuropathology of ADHD involves frontal-striatal dysfunction, this study investigated the possibility that aspects of physical overactivity in ADHD could be a result of a "utilization behavior syndrome".

Theories of this utilization behavior that claim the syndrome results from an imbalance between medial (frontal; voluntary, goal-directed) and lateral (parietal/visual; automatic, reactive) motor systems were also addressed. Results revealed high levels of utilization behavior specifically characterize hyperactivity in ADHD, and that motor overactivity in ADHD is not simply a result of generally heightened activity levels. Levels of utilization behavior were statistically associated with severity of hyperactive symptomatology as reported by parents of children with ADHD. Furthermore, utilization behavior was significantly related to difficulties on tasks thought to be dependent on the functioning of the medial, but not the lateral, motor system. This supports theories that utilization behavior, at least in ADHD, could be a result of disinhibition of the lateral motor system due to dysfunction within the medial motor system.

Examiners

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Introduction

ADHD and Physical Overactivity

With prevalence rates of around 3-7% of school children (NIH Consensus Development Program, 1998; Szatmari, 1992), Attention Deficit Hyperactivity Disorder (ADHD) is one of the most frequently diagnosed psychiatric disorders of childhood. Given the prevalence of this disorder within the pediatric population, considerable research interest has focused on better understanding the functional basis and pathophysiology of ADHD. Interestingly, there has been less research regarding the etiology and nature of the cardinal symptoms of physical overactivity (hyperactivity) within ADHD.

Although high degrees of motor activity are found in normal school-age children, the diagnosis of ADHD is generally restricted to pervasive, developmentally inappropriate levels of inattention, impulsivity, and motor restlessness (Gorenstein & Mammato, 1989). The Fourth Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), the current diagnostic standard for psychiatric and psychological practice in North America, categorizes ADHD into 3 subtypes; inattentive, hyperactive-impulsive, and combined variants (American Psychiatric Association, 1994). ADHD, hyperactive-impulsive and/or combined types, of primary interest in this investigation, are externalizing disorders characterized by problems with disinhibition, impulsivity, and excessive motor activity (Goodyear & Hynd, 1992). Motor disinhibition and impulsivity are evident in developmentally inappropriate levels of fidgetiness, difficulties staying seated, inappropriate/excessive movement, difficulties waiting one's turn, and excessive fiddling with objects (Barkley, 1997a). Further, anecdotal and observational evidence

indicates that children with ADHD have great difficulty restricting their behavior to conform to instructions and rules, and with deferring gratification and resisting temptation (Barkley, 1997a).

Motor overactivity, impulsivity, and disinhibition are among the more obvious symptoms of ADHD. Indeed the most salient differences between ADHD and non-hyperactive children are reported in activity level and motor disinhibition (Tryon, 1993). Some theorists have proposed that ADHD is uniquely characterized by overactivity and difficulties with motor regulation (Halperin, Matier, Bedi, Sharma, & Newcorn, 1992), with these symptoms distinguishing ADHD from other psychiatric disorders. In contrast, inattention is thought to be a relatively nonspecific symptom, present in a variety of psychiatric illnesses (Halperin et al., 1992). Despite recognition of the salience of these symptoms in ADHD, there is at present no clear understanding of the typology or etiology of physical overactivity within this population.

Although there have been many theories regarding the core deficit in ADHD, many contemporary researchers agree that the central problem appears to be a deficit in behavioral inhibition (Barkley, 1997a, 1997b; Pennington & Ozonoff, 1996; Quay, 1988; Schachar, Tannock, & Logan, 1993; Schachar, Tannock, Marriott, & Logan, 1995a). Converging lines of evidence have supported a primary impairment in the ability to inhibit/delay behavioral responses. Behavioral inhibition deficits have been associated with a variety of symptoms in ADHD, including problems with impulsivity and motor control. Laboratory investigations of cognitive and behavioral deficits in ADHD have corroborated the ubiquitous nature of behavioral inhibition difficulties within this population, and have generated a number of different theories regarding the exact nature

of this inhibitory deficit (Oosterlaan & Sergeant, 1996; Quay, 1997; Schachar et al., 1995a). Barkley (1997a, 1997b) has presented one of the more comprehensive theories of behavioral inhibition in ADHD, incorporating research from a variety of sources.

According to Barkley (1997b), behavioral inhibition is comprised of 3 interrelated processes that include: 1) inhibition of an initial prepotent response to an event, 2) interference control, or protection of the delay period from disruption by competing events and responses, and 3) stopping of an ongoing response, permitting a delay in the decision to respond. Barkley provides evidence to suggest that children with ADHD demonstrate difficulties in all three dimensions of inhibition, thus supporting the primacy of a severe and global deficit in behavioral inhibition.

In support of Barkley's first aspect of behavioral inhibition, problems with inhibiting a prepotent response have been documented in a number of studies that have used Go/No Go and Continuous Performance Test (CPT) paradigms (Barkley, DuPaul, & McMurray, 1990; Barkley, Grodzinsky, & DuPaul, 1992; Grodzinsky & Diamond, 1992; Iaboni, Douglas, & Baker, 1995; Mariani & Barkley, 1997; Shue & Douglas, 1992; Trommer, Hoeppner, & Zecker, 1991; Voeller & Heilman, 1988).

Corroborating deficits in Barkley's second aspect of inhibition, naturalistic observations of children with ADHD suggest increased susceptibility to distraction by external stimuli. Such difficulties with interference control have been corroborated in a number of studies investigating performance of children with ADHD on Stroop-type paradigms (Boucagnani & Jones, 1989; Grodzinsky, 1990 cited in Barkley, Grodzinsky, & DuPaul, 1992).

Finally, problems in inhibiting an action that is already in progress have also been documented in children with ADHD, primarily through the use of "Stop-Signal" paradigms (Logan, 1984 cited in Schachar, Tannock, & Logan, 1993; Oosterlaan & Sergeant, 1996; Pliszka, Borcherding, Spratley, Leon, & Irick, 1997; Schachar & Logan, 1990; Schachar, Tannock, Marriott, & Logan, 1995b; Tannock, Schachar, Carr, Chajczyk, & Logan, 1989). Problems in inhibiting ongoing responses have also been demonstrated on tasks such as the Wisconsin Card Sorting Test (WCST), in which children must stop an ongoing response pattern and shift to a more effective one (Barkley et al., 1992; Sergeant & van der Meere, 1988). The difficulty that ADHD children have in inhibiting primed responses has been interpreted as reflecting deficits at a motor output/inhibition stage (Leung & Conolly, 1997).

According to Barkley's theory (Barkley, 1997a, 1997b), the above deficits in behavioral inhibition have a notable negative impact on the regulation of behavior and motor control. Barkley hypothesizes that the capacity for behavioral inhibition is fundamental, providing the foundation for four intermediate executive abilities: 1) working memory, 2) internalization of speech, 3) self-regulation of affect, motivation, and arousal, and 4) reconstitution (i.e., the analysis and synthesis of internally represented information and the behavioral structures associated with that information). It is suggested that deficits in behavioral inhibition will lead to secondary impairments in the four intermediate neuropsychological abilities that depend on behavioral inhibition for their effective and efficient execution. Impairments in these executive functions, in addition to the primary deficit in behavioral inhibition, are hypothesized to impact "motor control/fluency/syntax" or the guidance and regulation of motor behavior. The four

executive functions are hypothesized to serve to shift the control of behavior from external contingencies to control by internally represented information. Barkley postulates that children with ADHD should be more influenced by external context, and less well controlled by internally represented information.

Clinical neuropsychological studies that have investigated difficulties with behavioral inhibition and other aspects of executive function within ADHD populations have implicated dysfunction within frontal systems as the neuropathological basis for the condition. In addition, it has been long recognized that the behavioral phenotype of ADHD closely resembles that seen in individuals with documented frontal lobe pathology, and more specifically with lesions to prefrontal cortex (Benson, 1991; Mattes, 1980). The "frontal lobe hypothesis" of ADHD has been supported by many neuropsychological investigations demonstrating impaired performance in ADHD children on tasks presumed to tap the functions of the frontal lobes (Barkley, 1997a; Chelune, Ferguson, Koon, & Dickey, 1986; Gorenstein & Mammato, 1989; Grodzinsky & Diamond, 1992; LaPierre, Braun, & Hodgins, 1995; Pennington & Ozonoff, 1996; Shue & Douglas, 1992). For example, ADHD children, like patients with frontal lobe lesions, often manifest problems in behavioral control in the context of relatively preserved intelligence and cognitive functioning in other domains (Shue & Douglas, 1992). Behavioral difficulties seen in both ADHD and frontal lobe populations include, but are not limited to, problems with attention, inhibition, impulsivity, disinhibition, hyperactivity/motor restlessness, motor regulation, and goal-directed behavior (Barkley, 1997a; Chelune et al., 1986; Goodyear & Hynd, 1992). Heilman and colleagues (1991)

proposed that evidence of neglect, motor impersistence/restlessness, and failures of response inhibition in ADHD suggest a pathophysiologic substrate for ADHD that may primarily involve dysfunction in right-sided frontal-striatal systems.

Structural and functional neuroimaging studies have supported the notion that pathophysiology of ADHD involves dysfunction in frontal-striatal systems, although any specific lateralization of this deficit has yet to be substantiated (Casey, in press; Casey et al., 1997; Tannock, 1998). Frontal-striatal pathways are thought to be important substrates for various aspects of behavioral inhibition and motor control (Alexander, Crutcher, & DeLong, 1990; Cummings, 1993; Groenewegen, Wright, & Uylings, 1997). These circuits, including the basal ganglial thalamocortical pathways that run from the prefrontal cortex through the basal ganglia and thalamic nuclei, have been associated with the voluntary control of motor activity and suppression of inappropriate action/behavior (Kroptov & Etlinger, 1999).

Regional Cerebral Blood Flow (rCBF) Computer Tomography (CT) studies, exploring brain metabolic activity in ADHD, have documented decreased blood flow to prefrontal regions and the pathways that connect prefrontal areas with the limbic system (via the anterior striatum; Zametkin et al., 1993). Hypoperfusion has been documented in the caudate nuclei, which are part of frontal pathways thought to mediate motor regulation. Blood perfusion within these areas increased following the administration of Ritalin (Lou, Henriksen, Bruhn, Borner, & Nielsen, 1989). In addition, investigations using Positron Emission Tomography (PET) have identified reduced cerebral glucose utilization in the frontal lobes in individuals with familial ADHD (Zametkin et al., 1990). Significant correlations have been documented between diminished frontal metabolic

activity and severity of ADHD symptoms (Zametkin et al., 1993). An investigation using Single Photon Emission Tomography (SPECT) brain imaging also documented abnormalities of metabolism in frontal regions within ADHD (Sieg, Gaffney, Preston, & Hellings, 1995), particularly in the left hemisphere. Again, the administration of Ritalin led to increased striatal perfusion and to notable clinical improvement.

Although gross structural imaging of the brain (CT) has not consistently revealed differences between ADHD and non-hyperactive controls (Shaywitz & Shaywitz, 1984), finer resolution Magnetic Resonance Imaging (MRI) techniques have documented abnormalities in brain regions implicated in frontal-striatal circuits. Hynd and colleagues (1990) used MRI to image the brains of children with ADHD, dyslexia, and normal controls. Results indicated that the brains of children with ADHD demonstrated a reversal of normal (left < right) frontal asymmetry. Examinations of the corpus callosum, have revealed smaller anterior (frontal) callosal regions associated with ADHD. Children with ADHD are found to have a smaller corpus callosum "particularly in the area of the genu and splenium, and in the area just anterior to the splenium" (Hynd et al., 1991b). Baumgardner and colleagues (1996) demonstrated that ADHD is associated with significant decreases in the area of the rostral body (anterior portion) of the corpus callosum. Studies of caudate nucleus morphology have also revealed abnormalities in ADHD (Roeltgen & Schneider, 1991). Hynd et al. (1993) and Filipek et al. (1997) reported that the left caudate nucleus is smaller in children with ADHD. Mataro and colleagues (1997) documented bilateral dysfunction in the caudate nuclei, possibly in association with impaired performance on attentional and behavioral measures (Mataro, Garcia-Sanchez, Junque, Estevez-Gonzalez, & Pujol, 1997). In contrast, other groups

have documented smaller right caudate nuclei in boys with ADHD (Castellanos et al., 1994; Castellanos et al., 1996). Casey and colleagues, using fMRI (Casey, 1999; in press), have investigated the neuroanatomical loci responsible for behavioral inhibition deficits in ADHD, and have found statistically significant correlations between various aspects of behavioral inhibition and caudate, prefrontal, and globus pallidus volumes. According to these investigators, children with ADHD display neurophysiological abnormalities in certain basal ganglial thalamocortical circuits (frontal-striatal pathways), particularly in the right hemisphere. Dysfunction in these circuits is believed to be directly related to behavioral inhibition deficits in ADHD.

In sum, despite some disagreement regarding the nature of unusual asymmetry in ADHD, most studies have documented smaller prefrontal cortical regions, smaller caudate volumes, and abnormalities in prefrontal-striatal circuits in ADHD. Although these frontal-striatal networks likely influence many aspects of behavior (which have not yet been clearly identified), research has shown that these networks are particularly important in the control of attention, inhibition, and motor intentional behavior (Hynd, Hern, Voeller, & Marshall, 1991a). Indeed, some authors have conceptualized ADHD as a disorder specifically of neural systems subserving the regulation of motor control (Hynd et al., 1991a; Hynd et al., 1991b; Niedermeyer, 1998; Niedermeyer & Naidu, 1997; Niedermeyer & Naidu, 1998).

As stated above, motor overactivity, disinhibition, and impulsivity are cardinal and indeed diagnostic symptoms of ADHD. Naturalistic assessments of the behavior of children with ADHD have documented higher than normal levels of motor activity (Porrino et al., 1983). Not only do ADHD children display quantitatively higher activity

levels, but also their activity is qualitatively more inappropriate and intrusive (Porrino et al., 1983). Hyperactive children also appear less able to inhibit their activity in accordance with instructions and encouragement to do so (Ullman, Barkley, & Brown, 1978), and demonstrate more off-task behavior, out of seat behaviors, and forbidden "touching of objects" than that seen in average children (Barkley, 1991). Given the prominence of motor regulation problems in ADHD, and documented dysfunction in frontal-striatal circuits, it is possible that some of the disinhibited motor behaviors seen in ADHD could be a result of what has been termed frontal lobe "utilization behavior" (Barkley, 1997a).

Utilization behavior

Utilization behavior is a phenomenon that has been demonstrated in individuals with dysfunction in the frontal areas of the brain. First coined by L'hermitte (1983), the term "utilization behavior" refers to a neurobehavioral syndrome that reflects instrumentally correct, yet highly exaggerated and inappropriate, motor responses to environmental cues and objects (Eslinger, Warner, Grattan, & Easton, 1991; L'hermitte, Pillon, & Serdaru, 1985). Patients have been described as reaching out and automatically using objects in the environment in a manner that is "object-appropriate," but is inappropriate for the particular context. Utilization behavior, in addition to automatic grasping/manipulation of objects (manual grasping behavior) and inappropriate imitation of the behavior of others (imitation behavior), has at times been described in the context of a more global "environmental dependency syndrome." The "environmental dependency syndrome" reflects notable deficits in personal control of action and a striking over-reliance on external social/physical environmental stimuli for guiding one's

behavior (L'hermitte et al., 1985). Description of utilization behavior have included situations, for example, in which a patient uses an object in its intended way (i.e., a patient reaches across the examining table, grasps the examiner's cup, and then places the cup to his/her lips as if to drink from it). Imitation behavior has been identified during situations in which a patient mimics gestures first produced by the examiner (i.e., the examiner runs his/her fingers through his/her hair and the patient then does the same). The environmental dependency syndrome encompasses aspects of both utilization and imitation behavior.

It has long been recognized that frontal lobe lesions can disrupt the ability to inhibit impulsive actions, and to maintain purposive and goal-directed behavior (Luria, 1973). Indeed, patients with frontal lobe damage often appear to be strongly controlled by irrelevant external stimuli, and have difficulty behaving in accordance with the plans or intentions that they have created (Luria, 1973). Along the same lines, most theoretical perspectives explain utilization behavior as resulting from an imbalance between frontal systems, felt to be important for internally motivated motor activity, and parietal systems important for motor activity in response to external or environmentally based stimuli (Brazzelli, Colombo, Della Sala, & Spinnler, 1994; L'hermitte et al., 1985; Shallice, Burgess, Schon, & Baxter, 1989), due to the loss of frontal executive controls. To date, most investigations of utilization behavior have been detailed case studies.

Motor control difficulties, motor programming problems, and compulsive motor behaviors in frontal lobe patients were described early on by Denny-Brown and colleagues (Denny-Brown & Chambers, 1958). Unrestrained motor responses to concrete stimuli, in the form of bilateral manual grasping behaviors, were interpreted as

evidence for a sensorimotor imbalance between the frontal and parietal lobes, representing the internal and external worlds, respectively. Frontal lobe damage, and the suppression of inhibitory functions of the frontal lobes, was believed to release parietal lobe activity. This phenomenon, termed "magnetic apraxia," provided a foundation for the later identification and description of the utilization behavior syndrome.

Utilization behavior was first clearly described by L'hermitte (1983) in an observation of six patients with either unilateral or bilateral lesions of the frontal lobes. L'hermitte presented a series of case studies that extended the notion of "magnetic apraxia" to include those instances in which tactile, visuo-tactile, and visual presentation of objects compelled the patient to grasp and use the objects according to an object-appropriate motor program (Brazzelli et al., 1994). Utilization Behavior was stimulated by placing a common object in the palm and fingers of a patient's hand or by holding out an object (e.g., a glass, a jug of water, a plate, a knife and fork, etc.) and enticing the patient to seize it. Patients with frontal lobe lesions automatically grasped and "utilized" these objects in an appropriate manner, even when object use was inappropriate for that particular situation. Patients were also described as manually grasping and manipulating objects in a non-purposeful manner. Utilization behavior and other environmentally driven behaviors were interpreted as resulting from impaired balance between frontal-voluntary (i.e., intrapersonal, motivational, reward driven) and parietal-reactive (i.e., environment-driven, extra-personal, reflex driven) systems. More specifically, all humans display a typical sequence of behavioral responses upon viewing an object, including attending to the object, orienting oneself towards the object, approaching the object, exploring (identifying) the object, and then utilizing the object. This behavioral

sequence is believed to be controlled by posterior parietal cortex, which can be inhibited by frontal processes under situations in which utilization of the object would not be the appropriate response (Ghika, Tennis, Growdon, Hoffman, & Johnson, 1995). Based on an analysis of lesion sites in these six cases, L'hermitte concluded that utilization behavior arises in association with unilateral or bilateral frontal lesions. More specifically he claimed that utilization behavior had an inferior frontal localization, reflecting damage to orbital frontal surfaces and possibly the caudate nuclei. However, although one might expect to see some utilization behavior following damage to the frontal regions described above, the striking behavioral syndrome described by L'hermitte is probably a rare occurrence.

In a subsequent investigation, L'hermitte studied 125 patients with focal and diffuse cerebral lesions resulting from a variety of neurological processes (tumor, trauma, vascular lesions, degenerative disorders etc.; L'hermitte, Pillon & Serdaru, 1985). Patients were screened for evidence of environmental dependency, including both imitation behavior and utilization behavior, through neurological/neuropsychological testing and behavioral observations. Within this sample, 40 patients were identified as displaying imitation behavior, 35 patients as demonstrating imitation behavior and utilization behavior, and 50 patients as neither exhibiting imitation behavior nor utilization behavior. Results of clinical examinations, neuropsychological testing, and behavioral observations revealed that all patients exhibiting imitation behavior or utilization behavior displayed these behaviors within the context of a more global "frontal syndrome." Imitation behavior and utilization behavior were believed to reflect an imbalance between dependence on and independence from external stimuli, and

differed only in terms of their level of severity and their respective dependence on the social versus the physical environment. Interestingly, individuals with disseminated lesions incorporating both frontal and parietal systems did not demonstrate utilization behavior or imitation behavior, suggesting these behaviors are associated specifically with damage to the inferior frontal cortex in the context of intact parietal function. The second part of this investigation supported the ecological validity of the imitation behavior and utilization behavior constructs through their elicitation in real-life situations (L'hermitte, 1985).

Utilization behavior has also been described in an individual with bilateral inferior/mesial frontal lobe lesions as a result of an ischemic episode involving both anterior cerebral arteries (Shallice et al., 1989). This study additionally addressed concerns regarding L'hermitte's procedures for eliciting utilization behavior. In particular, it was suggested that the examiner's unusual behavior of placing objects in the clients' hands may have led patients to a mistaken understanding of what was expected of them (L'hermitte et al., 1985). In other words, some were concerned that L'hermitte's procedures for inducing utilization behavior may have confused the patients and led them to the erroneous assumption that the examiner wished them to use the objects. To address this issue, this investigation employed two different procedures for eliciting utilization behavior; L'hermitte's original procedure (termed "induced utilization behavior") and an additional incidental procedure ("incidental utilization behavior") in which there was presumed to be no explicit or implicit expectation that objects should be used. During the incidental procedure, the patient was instructed to carry out neuropsychological tests and other tasks in the presence of objects that could act as

vehicles for utilization behavior. Behavioral observations of this patient revealed incidental utilization behavior. These behaviors were subsequently categorized as: 1) toying: a single action in which an object was manipulated but not in a purposeful way, 2) complex toying: actions involving two objects used together but not for the purpose for which they were designed or in a complete way, and 3) coherent activity: a set of actions integrated in an appropriate way with respect to the two objects. Utilization behavior was also elicited during the induced procedure, although these two conditions were not compared. Consistent with L'hermitte's claim (L'hermitte et al., 1985), the patient had an inferior frontal lesion localization.

Brazzelli and colleagues (1994) presented a case of utilization behavior in a 16-year-old girl with herpes encephalitis and bilateral damage of the frontal lobes. Observations during neuropsychological testing revealed notable motor hyperactivity and high levels of manual grasping behavior (MGB) and utilization behavior. Using Shallice et al.'s (1989) incidental procedure, utilization behavior was identified and classified according to Shallice et al.'s (1989) categorization scheme, described above. Interestingly, performance on neuropsychological measures of attention and executive function was within normal limits, refuting the notion that utilization behavior is only present in the context of severe executive dysfunction. L'hermitte's hypothesized neural basis for utilization behavior was again supported, in that the bilateral lesion involved orbito-mesial cortex, with sparing of dorsolateral prefrontal cortex and the basal ganglia. The authors hypothesized that utilization behavior may be secondary to bilateral disruption of thalamo-prefrontal connections.

A study of environment-driven responses in seven patients with progressive supranuclear palsy (PSP) provides additional evidence regarding the neuropathological substrate for utilization behavior (Ghika et al., 1995). PSP is a Parkinsonian syndrome, with supranuclear opthamoplegia, that is typically nonresponsive to antiparkinsonian medications. The neuropathology of PSP is thought to involve dysfunction in the frontal lobes and basal ganglia (the frontal-striatal system). The behavioral sequelae of PSP include several motor signs, cognitive difficulties (particularly executive dysfunction), and complex motor behaviors, including compulsive manipulation of tools and environmental dependency with utilization behavior. Results of this investigation indicated numerous instances of grasping behaviors and utilization behavior when objects were placed in front of PSP clients. These behaviors persisted even when clients were instructed to refrain from touching the objects. In conjunction with PET evidence, utilization behavior in PSP was interpreted as resulting from weakened descending inputs from the frontal lobes, which are typically responsible for set, choice, timeliness, and initiation of motor responses to extrapersonal stimuli. Frontal-striatal dysfunction leads to disinhibition of parietal chain behaviors, releasing automatic motor behavior in response to external stimuli.

Disinhibited responding to objects and environmental cues were described in a case of paramedian thalamic infarction, suggesting that utilization behavior could also have a thalamo-frontal basis. Eslinger and colleagues (Eslinger et al., 1991) described a case of a woman with bilateral encephalomalacia affecting the medial thalamus. Behavioral observations indicated high levels of distractibility and disinhibition, and excessive manipulation of objects in the external environment. On examination, with and

without induction, the patient excessively utilized objects and demonstrated great difficulty regulating her interaction with the environment. Neuropsychological evaluation revealed executive impairments in concentration and mental control, and notable difficulties with focusing, maintaining, and shifting attention. Notable deficits were also noted in motor programming. Follow-up evaluation at four months indicated that the patient continued to display utilization behavior. The fact that utilization behavior may also occur with focal damage to the paramedian thalamic region is not surprising given the role of the thalamus in the regulation of human instrumental behavior and independence from the environment. On the other hand, PET studies have demonstrated hypometabolism in frontal regions after thalamic infarction, supporting a possible diaschisis effect on the frontal lobes (i.e., dysfunction within the frontal lobes due to damage/dysfunction within a distant yet connected structure).

A severe frontal syndrome, including utilization behavior, was described in a patient with an infarct of the left anterior cingulate gyrus-caudate complex and head of the right caudate nucleus (Degos, da Fonseca, Gray, & Cesaro, 1993). Clinical behavioral features included distractibility, docility, emotional unconcern, perseveration, anterograde amnesia, MGB, prehension, and utilization behavior. Fronto-cortico-caudate projections were implicated in the genesis of utilization behavior.

Anatomically the anterior cingulate gyri are connected with the frontal (prefrontal, orbital and premotor) cortex, supplementary motor area, thalamus, mesencephalic reticular formation, amygdala, and striatum. The anterior cingulate gyrus also has connections with area 7, which is involved in the direction and spatial localization of behaviorally relevant visual stimuli, and which drives movements towards

salient visual stimuli. Recent PET studies have documented increased blood flow in the medial frontal lobes (which have strong connections to the anterior cingulate gyrus) when individuals are completing tasks that require the selection of action and inhibition of habitual responses. This research indicates a relationship between the anterior cingulate gyrus and the internal generation of action (Frith, Friston, Liddle, & Frackowiak, 1991).

Imitation behavior (imitation of gestures produced by the examiner) and utilization behavior were investigated in 78 neurologically impaired patients with focal hemispheric lesions documented on CT (De Renzi, Cavalleri, & Facchini, 1996). Patients were separated into a "frontal group," for whom damage encroached on the frontal lobes, and a "non-frontal" group, for whom the frontal lobes were spared. Utilization behavior was invoked through both incidental and induced procedures, and imitation behavior was elicited through the performance of various gestures by the examiner. Results indicated that imitation behavior was generally associated with damage to upper medial and lateral frontal cortex, and possibly with damage to striate structures. Within this sample utilization behavior was much more rare than imitation behavior, and generally took the form of toying or non-purposeful manipulation of objects (MGB). MGB includes fiddling with objects yet not using them in any appropriate way (e.g., running one's fingers over the bristles of a brush or moving the brush around in one's hands). The authors concluded that if utilization behavior occurs it is typically within the context of imitation behavior, and that utilization behavior may reflect a more severe degree of impairment than imitation behavior.

Utilization behavior and concomitant motor neglect were reported in association with bilateral frontal lobe damage in a patient with primary cerebral malignant lymphoma

(Fukui, Hasegawa, Sugita, & Tsukagoshi, 1993). The patient presented primarily with bilateral utilization behavior and imitation behavior, and motor neglect of the left arm. During the evaluation pathological grasping on visual or tactile presentation of objects, non-utilization of the left extremities, and the automatic use of objects despite prohibitions not to touch, were evident. In most situations reactions consisted of automatic reaching, holding, and using objects for their purpose, particularly with the right hand. Following treatment, MGB was still present in the right hand and became more prominent in the left hand, use of the left hand increased, and automatic utilization of objects became less conspicuous in the right hand and more-so in the left hand. Following recurrence of the tumors the bilateral grasp reflex, MGB, and automatic utilization of objects became again more prominent in the right hand. The non-use of this patient's left extremities was believed to be associated with motor neglect, often seen following mesial frontal lesions. MGB and utilization behavior were interpreted as resulting from the imbalance between internal motivations and dependence on exogenous stimuli. These authors suggest that utilization behavior never occurs without bilateral MGB, both resulting from release of the parietal lobes in the context of frontal system dysfunction.

Utilization behavior has also been reported in a patient with a right thalamic infarction (Hashimoto, Yoshida, & Tanaka, 1995). Functional neuroimaging revealed hypoperfusion in the right cerebral cortex, particularly in frontal areas, as a result of interrupted projections from the thalamus to frontal/orbital prefrontal cortex. Behavioral observations of the patient indicated marked motor impersistence, a bilateral, but right hand predominant, automatic grasp reaction, and excessive utilization of objects. When

instructed not to use the objects the client would immediately discontinue the behavior, yet resume utilizing the objects shortly after. Following recovery, 2-month follow-up revealed that the motor impersistence, instinctive grasp reaction, and utilization behavior had resolved.

Utilization behavior and imitation behavior were prominent signs in a case with bilateral frontal lobe infarction due to moyamoya disease (Hoffmann & Bill, 1992). Predominantly found in Japanese individuals, moyamoya disease is characterized by progressive neurological disability as the result of occlusion and small hemorrhages in the vessels at the base of the brain. The disease has an initial predilection for the anterior circulation. In this investigation, CT scans revealed bilateral hypodensities in the distribution of the territory of the anterior cerebral artery. Although performance during standard neurological and neuropsychological examination was within normal limits, behavioral sequelae included inappropriate behavior, an apathetic and aloof demeanor, and imitation behavior and utilization behavior. To test for the environmental dependency syndrome, the client was placed in a number of familiar situations in which both imitation behavior and utilization behavior were elicited. Imitation behavior, utilization behavior, and environmental dependency resolved gradually over a period of six months following treatment, coinciding with 60-70% shrinkage of the anterior lobe hypodensities. The authors described the environmental dependency syndrome as an extension and a more severe form of imitation behavior and utilization behavior. Environmental dependency is more likely to be elicited in the familiar and more complex situations of everyday life. This study suggests that imitation behavior and utilization

behavior may be some of the earlier and subtler signs of bilateral prefrontal lobe dysfunction.

Finally, utilization behavior has frequently been reported in conjunction with the "Alien Hand Sign" (AHS) phenomenon. AHS has typically been described following unilateral lesions of medial frontal cortex, often in response to damage in the distribution of the anterior cerebral artery (Banks et al., 1989; Kaufer, Mendez, Mischel, Verity, & Benson, 1996). Although the specific "alien hand" is typically contralateral to a unilateral lesion, this syndrome also has been also reported in both hands in those with bilateral medial frontal lesions (Brust, 1996). The constellation of symptoms occurring in the context of the AHS phenomenon include manual grasping behaviors, inter-manual conflict, unilateral utilization behavior, and a phenomenon in which one hand performs seemingly voluntary movements that the individual cannot suppress and for which the individual does not feel ownership. Theoretical explanations of AHS propose that the syndrome reflects an imbalance between movements that are reactive to environmental change and self-initiated or internally generated movements. These two types of movements are thought to be balanced by the supplementary motor area (SMA), which when damaged leads to disinhibition of environmentally reactive movements in the form of "alien" behavior (Brust, 1996).

Based on a summary of case studies, the pathophysiology of utilization behavior appears to involve dysfunction in the frontal systems of the brain. More specifically frontal-striatal pathways, including the previously described basal ganglial thalamocortical circuits, appear to be involved (Brazzelli et al., 1994; Cummings, Goldberg & Podell, 1995; L'hermitte, 1983; L'hermitte et al., 1985; Shallice et al., 1989).

Interestingly, utilization behavior has not been reported following lesions encompassing both frontal and parietal cortex. This supports notions that utilization behavior reflects disinhibition of an intact parietal, externally based system, as a result of dysfunction in a frontal, internally based system. Theoretical accounts regarding the functional basis of utilization behavior have generally viewed this syndrome as reflecting disruption of the inhibitory influence of frontal systems on parietal lobe systems, relegating the control of behavior to the external environment. In other words, utilization behavior is a result of an imbalance between the internal and external control of behavior, due to impairment in the internal control system (Goldberg & Podell, 1995). One theoretical framework has conceptualized utilization behavior as resulting from imbalance between a medial motor system, which is responsible for internal control and goal-directed action, and a lateral motor system, which guides automatic responding to external environmental stimuli (Goldberg, 1985). Impairment in the medial (internal control) motor system leads to disinhibition of the lateral (environmentally responsive) motor system, resulting in utilization behavior.

The Medial and Lateral Motor Systems

Goldberg (1985) originally proposed the concept of a medial and a lateral motor system that work cooperatively to guide behavior. In elaborating this theory, Goldberg provided a wealth of supporting evidence, including animal research and clinical observations. Interestingly, although Goldberg's theory has frequently been cited in the research literature, and his framework has often been used to explain motor phenomena in various clinical disorders (Frith, 1987; Kopp & Rist, 1994), there has been little direct

empirical evaluation of the theory. As a result, many constructs within the theory are somewhat vague and difficult to describe.

It is widely held that the motor system is controlled by competition between different sources of action, some which reflect internal states and goals and others that reflect behavior in response to external stimuli. Primary motor cortex is the final tallying point for the competitive process between potential response options. Motor planning involves a variety of neural regions, the locus of control of the movement varying according to the extent to which an action is internally or externally guided. According to Goldberg (1985), internally generated, volitional action is mediated by a medial motor pathway, whereas a lateral motor pathway mediates responsive, environmentally induced motor acts. Under normal conditions, the lateral and medial pathways cooperate, with the lateral motor pathway dominating during tasks that depend on external cues (e.g., when one is required to perform movements under the guidance of visual, auditory, or somatosensory feedback), and the medial motor pathway dominating when a task is internally guided (e.g., when performing movement that arises out of one's internal context). Although Goldberg proposes that the lateral pathway functions downstream from the medial pathway, it is undecided as to whether these hypothesized pathways would function in parallel or in a sequential fashion.

As stated above, the hypothesized lateral pathway is thought to dominate during visually guided, externally based movement. This pathway is strongly sensory dependent, and produces externally contingent responses based on identification of objects in the environment. This pathway is concerned with perceiving/ recognizing

external input, and is used in the production of responsive action driven by the presence of stimuli in the immediate environment.

According to Goldberg, the lateral pathway runs from cortex, to cerebellum, to lateral thalamus, to lateral premotor cortex (PMC), to primary motor cortex (MI). The pathway is extensively innervated by parietal cortex and cerebellum, both of which have strong links with visuo-motor areas and which receive rich representations from other sensory channels.

In support of the lateral pathway, human functional neuroimaging studies indicate that higher metabolism in the lateral PMC is correlated with increased metabolism in the superior parietal lobe and cerebellum (Chauvel, Rey, Buser, & Bancaud, 1996). Further, rCBF investigations in humans demonstrate that the lateral pathway is more activate during performance of tasks dependent on extrapersonal reference systems (Goldberg, 1985). Therefore, this pathway appears well suited to coordinate movement with external sensory information, and to create a link between external stimuli and behavior. Research employing non-human primates has supported the association of the lateral motor pathways with externally based movement. Studies by Tanji and colleagues (cited in Mardsen et al., 1996) indicate increased activity in the lateral PMC in response to visual signals and motor actions driven by external stimuli. PET studies with non-human primates have demonstrated that premotor neurons are highly active during externally guided motor sequences (Goldberg, 1985) and lesions of lateral premotor cortex impair the ability to move in the direction signaled by an external cue (Mardsen et al., 1996).

In contrast, the medial motor pathway is thought to dominate during internally generated movements that are projectional (future-directed), goal-oriented, and context-

sensitive in nature. Guided by the internal representation of a desired action, this "medial" pathway is important for responding to the individual's motivational state and internal goals, and for translating intention into action. According to Goldberg (1985), the medial pathway is expected to have a number of important functions. First, this circuit is thought to function upstream from, and to exhibit inhibitory controls over, the lateral pathway. In other words, the medial pathway exerts control over environmentally contingent responsive action, and has a role in suppression of automatic responding to salient environmental cues. Second, the medial pathway is thought to play a role in internal self-monitoring of action and error correction, through dependence on primarily kinesthetic and proprioceptive feedback. Third, this pathway is believed to be important for generating an internal representation or mental image with which to guide behavior. Finally, the medial pathway is thought to be important in directing behavior based on internal context, by inhibiting extra-volitional actions that are inconsistent with goals or a prior instructional set (e.g., inhibition of habitual responding).

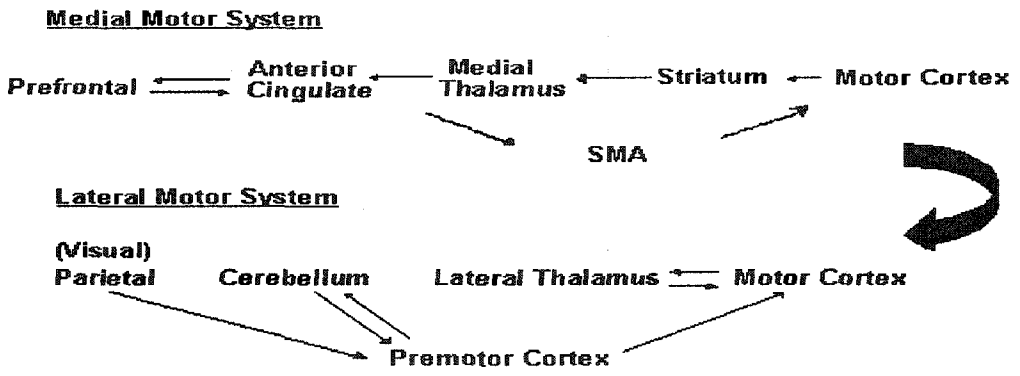
Goldberg hypothesized the medial pathway runs from frontal cortex, to the striatum, to the globus pallidus, to the inner thalamus, to the supplementary motor area (SMA), anterior cingulate cortex (ACC), and frontal cortex. Critical nodes within the medial motor pathway include the basal ganglia, SMA, and prefrontal cortex, although dysfunction/damage within any portion of the circuit would likely negatively influence the functioning of this pathway. The SMA appears to be a vital relay station within the medial pathway, receiving extensive projections from the prefrontal cortex, basal ganglia, and limbic structures (Goldberg, 1985). The SMA, located in the medial part of the PMC (area 6) (Passingham, 1996), appears well suited for coordinating internal sources of

activation, such as goals and motivation, with action (Goldberg, 1985; Mardsen et al., 1996; Passingham, 1996). The prefrontal cortex is also very important in this pathway, possibly forming decisions as to what action to perform when, while the SMA translates these decisions into action and initiates internally generated movements (Passingham, 1996).

In support of Goldberg's medial motor pathway, research has demonstrated that the SMA is very active during internally generated motor behaviors (Mardsen et al., 1996). Regional CBF studies in humans have documented activation of the SMA proportional to the degree of internally developed intentionality associated with the performance of a motor task. Investigations with non-human primates indicate that the SMA is disproportionately active during internally guided movements (Goldberg, 1985), and during the initiation/performance of movements when there are no external cues guiding behavior (Passingham, 1996). Indeed, there is evidence that primates with lesions to the SMA can perform activities with prompting by external cues, yet have great difficulty with internally generating movement without such prompting (Passingham, 1996). In addition, human ERP studies indicate that the SMA is important in the development of readiness to act based on internal drive tendencies (Goldberg, 1985). The medial motor pathway also appears to play a role when movements are self-paced versus externally guided. PET scanning studies with humans have demonstrated SMA activation during self-paced tasks, and much less activation during externally paced movements (Passingham, 1996). Further, human PET studies demonstrate high levels of activation in dorsal prefrontal cortex during self-paced conditions, not seen during externally paced tasks (Passingham, 1996). Finally, there is evidence that ventro-medial

frontal cortex and prefrontal areas, also part of the hypothesized medial motor pathway, have potent inhibitory roles in the selection of motor acts for goal-oriented behaviors (Ghika et al., 1995). Orbital-frontal cortex is thought to be an integral part of a basic limbo-thalamic system involved in inhibition (Guillem, N'kaoua, Rougier, & Claverie, 1996). Research with non-human primates has demonstrated that frontal lobes, in conjunction with striate cortex, exert inhibitory effects on gaze orientation and on other environmentally induced responses (Ghika et al., 1995). Evidence that lesions to medial frontal lobe, including anterior cingulate, do not influence reactivity of eye movements towards extraneous stimuli but rather lead to impairment of inhibition of reflex-like saccades (Hildebrandt & Zieger, 1995), further supports this contention. Animal cortical unit studies have indicated that the SMA plays a role in inhibiting sensory triggered motor output, based on prior instruction (Goldberg, 1985). Damage to the SMA leads to reduced anticipatory movements and the disinhibition of movements in reaction to environmental stimuli (Brust, 1996).

Figure 1 The Medial versus Lateral Motor Systems



According to Goldberg (Goldberg, 1985), the functional cooperation between medial and lateral motor pathways is critical for guiding motor behavior (see Figure 1). However, dysfunction in either pathway would result in an imbalance between these two systems and symptomatic behavior. With dysfunction in the medial motor system, and loss of medial inhibitory controls, one would expect disinhibition of the lateral motor system. This would lead to an excess of environmentally driven responding, such as utilization behavior and MGB. On the other hand, with dysfunction within the lateral motor system one would expect to see impairments in the ability to respond to stimuli within the environment. With regards to medial motor system dysfunction, studies with primates have documented transient forced grasping behavior, an inability to inhibit reaching movements evoked by visual stimuli, and an inability to inhibit environmentally conditioned behaviors inappropriate for context (Goldberg, 1985) in response to SMA lesions. In humans, clinical investigations have documented AHS following damage to medial frontal cortex or the SMA (Brust, 1996), and bilateral utilization behavior following bilateral frontal and orbital frontal lesions (Brust, 1996). In contrast, neither AHS nor utilization behavior has been reported following damage to premotor cortex or other structures within the hypothesized lateral pathway (Freund, 1996). In addition, one would expect to see other difficulties in association with dysfunction in the medial motor pathway, given the multitude of functions that the hypothesized medial motor pathway is thought to mediate. In particular, one might expect to see impaired motor self-monitoring and error correction, impaired ability to guide behavior from an internal

representation, impaired motor learning/sequencing, and impaired inhibition of habitual (prepotent) environmental responding.

The Present Study

ADHD is uniquely characterized by motor/physical overactivity (hyperactivity). However, despite a multitude of investigations regarding the pathophysiology and underlying nature of ADHD, we do not yet have a clear understanding of the characteristics of motor overactivity or the etiology of hyperactivity. Elucidation of the functional basis of physical overactivity in ADHD will be an important step in better understanding and managing this prevalent childhood condition.

Given the high levels of motor activity and impulsivity in ADHD, and evidence that the neuropathology of ADHD involves dysfunction in frontal-striatal circuits, it is possible that some of the excessive motor activity and disinhibition could be a result of frontal lobe utilization behavior. According to Barkley (1997b), children with ADHD might demonstrate utilization behavior given their difficulty with the internal control of behavior, and susceptibility to external circumstances. Indeed, children with ADHD have been described as demonstrating not only quantitatively, but also qualitatively distinct problematic motor behavior, when compared with non-hyperactive children. Further, the neuropathology of ADHD involves the same circuits as those implicated in utilization behavior. Therefore, one primary goal of this investigation was to determine if some of the physical overactivity in ADHD is characterized by utilization behavior. It was hypothesized that children with ADHD would demonstrate more instances of utilization behavior than children without ADHD. To rule out the possibility that ADHD children touch more objects because they are in general simply more active, instances of other

types of motor behavior were also coded (e.g., self-touching). These other motor behaviors were not expected to differ between ADHD and non-hyperactive controls. To address concerns about traditional utilization behavior paradigms, levels of utilization behavior were investigated under "instruction" and "no instruction" conditions, with no differences anticipated between the two conditions, that is some children were specifically told 'not to touch' objects.

The physical overactivity characteristic of children with ADHD is also consistent with Goldberg's hypothesis (1985) of what would be expected given an imbalance between the medial and lateral motor systems. The neuropathology of ADHD involves structures thought to be part of the proposed medial motor pathway. Therefore, an additional goal of this investigation was to determine if children with ADHD demonstrate impairments in Goldberg's postulated medial motor system. It was hypothesized that ADHD children would manifest dysfunction in this system, displayed through several distinct lines of evidence. First, ADHD children were expected to demonstrate deficits in certain aspects of motor inhibition, particularly inhibition of a motor response incompatible with visual feedback. Second, in comparison to controls, children with ADHD were expected to demonstrate impaired motor self-monitoring and guidance of motor behavior by internally represented information. Finally, children with ADHD were expected to display difficulties with motor learning and sequencing. All of these aspects of motor control have been hypothesized to be associated with the functioning of the medial motor system (Goldberg, 1985).

Finally, the present study aimed to address Goldberg's claim that an imbalance between the proposed medial and lateral motor systems should lead to environmentally

driven-responding, including utilization behavior. Within the ADHD population, it was hypothesized that utilization behavior would occur as a result of dysfunction in the proposed medial motor system. Given this, first it was hypothesized that utilization behavior would occur during verbal tasks but not during visual-manual tasks when the lateral system is engaged. That is, object use would not occur when the visual/lateral motor system is engaged in a cognitive task. Second, it was predicted that there would be much higher levels of utilization behavior directed towards objects that were directly in sight versus those which were out of sight. Utilization behavior would be anticipated only in response to objects directly in sight, given that utilization behavior is thought to result from disinhibition of the lateral motor or visually-based motor system which guides automatic responding to objects that one. Third, it was anticipated that children with ADHD would exhibit higher levels of object directed (utilization behavior) versus self-directed (self-touching behaviors). More specifically, given disinhibition of the lateral system children with ADHD would be expected to demonstrate more motor behaviors in response to physical stimuli that they can see (objects). In addition, it was anticipated that hyperactivity is specifically comprised of utilization behavior and not merely a result of higher levels of motor activity in general. Fourth, it was hypothesized that there would be an association between utilization behavior and impaired performance on those motor tasks selected to measure the functioning of the medial motor system. That is, higher levels of utilization behavior would be associated with greater levels of dysfunction within the medial motor system.

Methods

Participants

The sample consisted of two groups of children, ranging in age from 6 to 12 years. The first group was composed of 32 children with Combined Type ADHD, who were compared with a group of 31 control children.

The majority of children in both the ADHD and control samples were recruited from 22 different schools across three school districts within the Capital Regional District of Vancouver Island. Teachers within each participating school distributed flyers to all children within their classrooms and interested families were asked to contact the University of Victoria. A brief telephone interview, which inquired about a history of attention problems, learning challenges and medical/psychiatric difficulties, was used for screening purposes and initial decision-making regarding possible inclusion of children in either the control or ADHD samples. Written informed consent was obtained from parents of all participants, and written consent/verbal assent was obtained from each child volunteer. Children and their parents were compensated with a small monetary stipend of $5.00 each. Inclusion in the ADHD sample was based on four separate diagnostic indicators. First, all children had previously been given a diagnosis of ADHD by a qualified health professional. Second, all children met DSM-IV criteria for present ADHD, combined type, based on a structured interview for parents administered by the investigator, the Diagnostic Interview for Children and Adolescents (DICA; Reich et al, 1997). Third, parents were asked to a complete a commonly used and standardized questionnaire, which measures children's behavioral difficulties and attention problems at home (The Conner's Parents Questionnaire; Connors, 1995). Finally, teachers were

asked to complete a similar screening questionnaire for behavioral and attentional difficulties at school (The Conner's Teacher's Questionnaire; Connors, 1995). There was a return rate of 81% for parent questionnaires, and 68% for teacher questionnaires. The low return rate for teacher questionnaires was primarily due to the fact that the study was conducted near the end of the school year. Of the questionnaires that were returned, ninety-six percent of the sample met criteria for ADHD based on the parent questionnaire, whereas 86% of the sample met diagnostic criteria for ADHD based on the teacher questionnaire. In certain cases it was not possible to obtain ratings of children's behavior off stimulant medication, given a long-standing history of medicinal management of ADHD symptomatology (30%). Based on parent forms that were returned, 85% of the ADHD children were taking Ritalin at the time of this study. All children with ADHD were required to be free of stimulant medication for at least 24 hours prior to testing. Of those screened, fifteen children were not included in the final ADHD sample of 32 children, as they did not meet full DSM-IV criteria for ADHD, combined type, based on the DICA. Given that the DICA provided stringent screening criteria for ADHD and that some of the parent/teacher rating scales were not returned, the decision was made to include children in the ADHD sample if they had a previous diagnosis of ADHD and if they met DSM-IV diagnostic criteria for ADHD, Combined Type, based on the parent interview (DICA). One hundred percent of children in the ADHD sample met the above criteria.

The community comparison group consisted of 31 children without a history of significant developmental, attentional, or behavioral problems. Parents of children in the control sample also completed the DICA. Parents and teachers of the comparison sample

were also required to complete the screening questionnaires for attention problems, described above. Children who were included in the control sample did not meet diagnostic criteria for a current or past history of ADHD, and they scored within 1 SD of the mean on all rating scales. There were return rates of 80% and 51% for parent and teacher questionnaires, respectively. Of children screened, six control children were excluded from the final community comparison group of 31 children due to behavioral concerns and/or medical complications. Control participants were matched with children within the ADHD sample based on age and gender.

The demographic characteristics of each sample are outlined in Table 1. The ADHD and control groups did not differ significantly in either age or gender. The ADHD sample consisted of 4 females and 28 males, whereas the control sample consisted of 4 females and 27 males.

The Wechsler Intelligence Scale for Children Third Edition (WISC-III) Vocabulary Subtest (Wechsler, 1991) was used to provide an estimate of verbal intelligence (VIQ). This measure was also selected to serve as the verbal task during which instances of utilization behavior were to be recorded. The Raven's Color Matrices Test (Raven, 1947, 1995) was used to estimate nonverbal intelligence (PIQ). Raven's Color Matrices served as the visual task during which levels of utilization behavior were to be recorded. An overall estimate of intellectual ability was calculated by averaging VIQ and PIQ estimates obtained on the WISC-III Vocabulary and the Raven's Colored Matrices subtests. Groups were found to differ significantly in the estimate of Verbal Intelligence (VIQ; $\underline{M}$ ADHD = 57.84 %ile, SD= 24.53; $\underline{M}$ Controls = 76.68 %ile, $\underline{SD}$ = 17.75; $\underline{t}(61) = 3.482$, $\underline{p} = .001$), as measured by the Vocabulary subtest of the Wechsler

Intelligence Scale for Children Third Edition (WISC-III). As a consequence the ADHD and control samples differed significantly in estimates of overall intellectual ability (t (61) = 2.917, $p < .01$), although estimates of intelligence for both groups fell solidly within the average range (M ADHD = 64.08 %ile, SD = 19.73; M Control = 76.92 %ile, SD = 14.78). The groups did not differ significantly on the Performance Intelligence (PIQ) estimate, as measured by Raven's Colored Matrices (M ADHD = 70.31 %ile, SD = 19.29; M Control = 77.16 %ile, SD = 18.00). There were no children with overall estimates of intelligence below a standard score of 80.

Table 1

Description of ADHD and Control Samples – Demographic Information

Measure	ADHD Group		Control Group			
	M	SD	M	SD	T	p<
Age	9.86	1.88	10.15	1.87	.60	ns
Estimate of Verbal IQ (WISC-III Vocabulary %ile)	57.84	24.53	76.68	17.75	3.48	.01
Estimate of Performance IQ (Ravens Matrices %ile)	70.31	19.29	77.16	18.00	1.46	ns
Estimate of Overall IQ (M Vocab. and Ravens %iles)	64.08	19.73	76.92	14.78	2.92	.05

Parents of all children were asked to complete the "Child History Questionnaire," which requests information about the child's medical, behavioral, and educational history. The control and ADHD samples did not differ reliably in total numbers of pregnancy complications or birth complications. However, the groups were found to differ significantly with regards to total number of childhood illnesses (t (49) = -3.76, $p<.001$; see Table 2), and in particular numbers of high fevers (t (49) = -2.19, $p < .05$), colds (t (49) = -2.92, $p <.01$), minor head injuries (t (49) = -2.02, $p<.05$), and headaches (t (49) = -2.70, $p <.01$). The difference between groups in terms of numbers of ear infections approached significance (t (49) = -1.95, $p = .056$). There were no children in

either sample who had a history of a significant head injury, as defined by loss of consciousness or need for hospitalization. The finding of increased childhood illnesses/minor accidents is common within ADHD samples. Overactive and uncooperative behaviors place these children at increased risk for incurring minor injuries. The groups did not differ significantly with regard to hand dominance (see Table 2).

Table 2

Description of ADHD and Control Samples – Medical History

Group	Medical History						
	No. Pregnancy Comp.		No. Newborn Comp.		No. Childhood Illness		LeftHanded
	M	SD	M	SD	Mean	SD	%
ADHD	1.23	1.24	.65	.69	4.65	2.56	12%
Controls	.79	.93	.58	.78	2.40	1.55	10%

Given the strong association of ADHD with learning disabilities, children with learning problems at school were not excluded from participating in the study. Inquiries about past and present educational performance revealed that, as expected, children within the ADHD sample had significantly more learning difficulties than children in the control group ($t(49) = -5.29$, $p < .001$) and were more likely to have attended behavioral adjustment class ($t(49) = -2.02$, $p<.05$). There were no statistically reliable differences between the samples in terms of participation in tutoring, enrichment/gifted programs, and language immersion (see Table 3). Groups were also equivalent in terms of total years of school experience (Grade in School, M ADHD = 4.19, SD = 1.92; M Control = 4.36, SD = 1.89, ns).

Table 3

Description of ADHD and Control Samples – Educational History

	Educational History				
Group	Learning Difficulties (%)	Tutoring (%)	Behavioral Adjustment (%)	Gifted (%)	Language Immersion (%)
ADHD	54	19	23	8	8
Controls	0	4	4	12	16

Procedures

All children were tested in the same research laboratory at the University of Victoria. The testing was conducted by two researchers who were not blind to the group status of participants. Testing occurred over one 2-hour session, which was divided in 2 hour-long parts conducted in different rooms: (1) the computer room and (2) the utilization behavior room. Participants were randomly assigned to start with activities within one of the two testing rooms, such that the hour-long part that each child began with was counterbalanced across the entire sample. Otherwise, the order of test administration and setup of each testing room was identical for all participants.

One examiner tested all children within the computer room, whereas the other examiner tested all children within the utilization behavior room. Within the computer room children were seated in front of a computer and asked to complete a number of computerized activities including two motor self-monitoring measures (Stirling Drawing Task (Stirling, 1999) Computer Drawing Task (Mlakar et al., 1994) and a measure of attention/inhibition (Continuous Performance Test; CPT; Connors, 1995).

The utilization behavior room was structured in such a way that children had easy access to objects that were readily "utilizable." To investigate if utilization behavior is directly related to disinhibition of the lateral (visual) motor system, objects in reach of

children were both within and outside of their line of sight. For this purpose a special testing table, with an "opening top" and a six-inch wide opening in the front, was constructed to allow children easy access to objects that they were aware of and that they could touch, yet were not in their line of vision. Each session within the utilization behavior room started with the testing table open such that children were able to view the objects inside the table. Once the child was seated the "opening top" of the testing table was closed.

To investigate the impact of object familiarity on utilization behavior a variety of objects that were either familiar (scissors, stapler, stopwatch, spotting scope, cup, brush) or unfamiliar (garlic press, wood working tool, clamp, wood planer, wine vacuum cork, ear syringe, table clamp) were selected. Objects were placed inside the table, on the top right hand side of the table, and on a shelf to the right of each child, with an equal number of familiar and unfamiliar objects either clearly visible or out of site. Objects were positioned in exactly the same location for all participants.

Each testing session was videotaped using two VHS cameras to record instances of utilization behavior and other examples of physical overactivity. The first camera was mounted high on the wall opposite the testing table and positioned facing the child to record motor behaviors above the table. The second camera was located underneath the testing table angled upwards through a plate glass bottom designed in the table, to give a clear view of children's hands inside the table and record utilization of objects from within the table.

To investigate the impact of instruction set/expectation on utilization behavior half of the sample was randomly assigned to an "instruction condition" and given

instructions at the beginning of testing not to touch the objects in or around the table. The other half of the sample was not given any instructions or direction regarding the objects.

Within the utilization behavior room, all children completed a verbal (WISC-III Vocabulary; Wechsler, 1991) and a nonverbal (Ravens Matrices; Raven 1947, 1995) reasoning task presumed to be similar in cognitive demand, to explore levels of utilization behavior during visual versus verbal activities. Other activities included a motor learning task (Kimura Box; Kimura, 1977), a computerized measure of inhibition (Motor Inhibition Task; Casey et al., 1997), and a motor self-monitoring task (Mirror Drawing). All children also participated in a non-structured activity within the utilization behavior room. During this activity, participants were left on their own to complete a series of simple math problems for a period of exactly 10 minutes.

Behavioral observations were the primary means of evaluating motor behaviors within the utilization behavior room. Instances of object-directed behaviors were coded according to Shallice's categorization scheme of utilization behavior (1989), which specifies that an instance of utilization behavior occurs when there is use of 1 or more objects lasting more than 1 second following the end of a previous instance of utilization behavior by at least 1 second. Behavioral categories of utilization behavior included: Toying, Complex Toying, and True Utilization Behavior. Toying was operationally defined as "a single action in which an object is manipulated but not in any purposeful way or for its intended use." Complex toying was defined as "the use of two objects in a linked way but in an incomplete fashion or not for the purpose for which both objects were designed," or the use of an object in a purposeful way but not for its intended

purpose. Observations of the children when they were touching the objects indicated that complex toying was typically purposeful in relation to objects, and that it generally occurred when children were not familiar with the exact function of an object. In this case children utilized the object in a manner that would be appropriate for a similar object of which they were familiar. Finally, True Utilization Behavior was defined as "a set of actions integrated in a typical fashion with respect to the relevant object(s)." Given that complex toying and true utilization behavior both involved purposeful manipulation of objects and that the occurrence of one behavior over the other appeared to be related to the children's familiarity with a particular object, these two categories were both judged to be examples of utilization behavior and were combined to yield an overall "Utilization Behavior" score.

Instances of self-directed motor behaviors (self-touching) were also recorded to rule out a general "activity level" confound. Self-touching was operationalized as "any behavior in which a child touches his/her upper body, face area, or clothing for more than 1 second following the end of a previous instance of self-touching by at least one second." Occurrences of resting one's head in one's hands and/or fidgeting with one's fingers were not considered examples of self-touching.

Both object-directed and self-directed movements were counted in 5-second intervals. Every behavior occurring over that five-second interval was checked once, and then not again until the next interval. In this study scores were calculated by tallying the number of object-directed (Toying, Complex toying, and True utilization behavior) behaviors in response to each object over different activities within the utilization behavior room. Self-directed motor behaviors (self-touching) were recorded in the same

way. Utilization behaviors and self-touching behaviors were rated across the entire testing session in the utilization behavior room, except for when children were completing the Kimura Box, Motor Inhibition, and Mirror Drawing Tasks. Behaviors were not rated during these activities because children would not have had the opportunity to engage in motor behaviors given the nature of each of these tasks.

Inter-rater Reliability.

Inter-rater reliability correlation coefficients were obtained through re-scoring of 20% of the videotapes by an independent examiner who was unfamiliar with the group membership of participants. As measured by single measure intraclass correlations, all reliability estimates were well above the required cut-off of 80% agreement between raters (see Table 4).

Table 4

Inter-rater Reliability Coefficients for Object-Directed and Self-Directed Motor Behaviors

	Single Measure Intraclass Correlations
Object-Directed Motor Behaviors	
Toying	.8714
Complex Toying	.9935
True Utilization behavior	.9340
Self-Directed Motor Behaviors	
Self Touching	.9718

Measure of Attention and Inhibition

Connors Continuous Performance Task (CPT; Connors, 1995). This is an approximately 15 minute computerized task in which participants were required to respond, by pressing a computer key, to the letters of the alphabet flashed, one at a time, across the centre of the computer screen. Participants were to withhold from responding upon seeing a

particular letter (the letter "X"). A number of summary indices were considered including errors of omission, errors of commission, variability of responding (i.e., consistency of an individual's responses over time), and risk taking (i.e., consideration of commission errors in the context of numbers of missed responses).

Measure of Motor Inhibition

Motor Inhibition Task. This task was a variant of Casey's computerized response selection task (Casey et al., 1997) that assessed the ability to inhibit a competing and prepotent motor response, requiring a response to stimuli based on incompatible or compatible motor mappings (Christ, 1999). In the compatible motor condition, participants were required to respond as quickly as possible to green, blue, or red arrows flashed, one at a time, on the left, middle or right side of the computer screen. The arrows were pointed in the left, up, or right direction, respectively. Participants were required to respond by pushing corresponding green, blue or red buttons positioned to the left, middle or right of a response apparatus. During the incompatible motor condition, participants were required to reverse their responding, and to respond to the green (left) and red (right) arrows by pressing the opposite buttons on the response apparatus. As in the compatible motor condition, children were required to respond to the middle (blue) arrow by pressing the middle (blue) button on the response apparatus. Summary scores consisted of the number of errors (responses in the wrong direction) made during the compatible and the incompatible motor conditions. Response time was recorded but not analyzed during the current study, as the most important indices were the error scores described above.

Measures of Motor Control and Monitoring

Mirror Drawing Test. This was a paper and pencil task that required children to trace a line around the perimeter of two geometric figures (square and diamond), in the presence of incompatible visual feedback from a mirror placed above the drawing. The task requires the ability to overcome incorrect visual information and instead rely on cognitive control and internal representations of which direction to draw. Participants' hands were covered and therefore the only visual information received was the reversed feedback from the mirror. For each drawing there was a control (copy) condition that required the child to trace a line around the figure outside of the mirror, and subsequently five trials of tracing each shape within the mirror. Due to observations that children appeared to be losing motivation for the task after the third trial of each drawing, scoring was based on the total number of drawing errors (lines drawn outside of the figure) from trials 1 through 3 and total time to complete the task, summed over both geometric figures.

Stirling Drawing Task (Stirling, 1999). Participants were asked to make a series of geometric designs on a computer stylus pad (with a stylus pen) with their hand out of sight. They were not able to see the drawings on the computer screen as they were making them. The computer then rotated 5 of the 6 drawings to different degrees, and children were required to choose from the 6 drawings, which was the exact one that they had created. In the first condition children were required to copy 7 designs shown on the computer. In the second condition children were asked to create 7 abstract drawings. In final (control) condition children again created their own abstract drawings, but were able to see the drawings on the computer screen as they were making them. Scoring was based on the total number of errors in each of the 3 conditions. Due to some difficulty

with the computer software that led to some missed trials, summary scores were reported in terms of the proportion of correct responses within each condition.

Computer Drawing Task. This was a computerized task based on a self-monitoring paradigm created by (Mlakar, Jensterle, & Frith, 1994). Children were asked to view a stimulus card depicting a geometric figure for 5 seconds. The stimulus card was then removed and children were required to draw the geometric figure on the computer screen using a joystick or keypad. Children were first required to reproduce a "u" shape under 7 different conditions. During the first two conditions children received normal feedback on the computer monitor and could see the geometric figure while they were creating it using the joystick and then the keyboard. This condition was considered a control condition, and assessed general motor control and placed less emphasis on motor monitoring ability. During the third and fourth conditions there was no visual feedback as children were reproducing the geometric figure, with the joystick and then keyboard. This portion of the task assessed the ability to use an internal representation to direct and monitor a motor plan. During the fifth and sixth conditions incompatible feedback (random lines) was presented on the computer screen as children used the joystick and then the keyboard to recreate the figure, assessing the ability to maintain a motor representation in the presence of distracting visual feedback. Finally, following the computer portions of the task, children were asked to draw the geometric figure on paper to ensure that errors were not due to difficulty with remembering the design. This procedure was then repeated for the second design (a cross shape). Summary scores included errors and time for each of the 7 conditions, summed over both drawings.

Motor Learning/Sequencing Task

Kimura Box (Kimura, 1977). This motor sequencing/learning task required that children perform a series of hand movements (push a button with their pointer finger, pull a lever with all 4 fingers, and push down a lever with their thumb) using a special box. The examiner demonstrated the motor sequence twice while providing a verbal description of the sequence. Children were then required to reproduce the sequence first with their dominant and then with their non-dominant hand, to a criterion of 10 consecutive trials. Children were given verbal feedback when they made an error. The measure was scored in terms of total numbers of errors (a movement out of sequence or the wrong movement) for each hand.

Results

Analysis of counterbalancing effects

As stated above, the initial portion of testing to which each participant was randomly assigned (utilization behavior room activities versus computer room activities) was counterbalanced across the sample. Using t-tests, there was no statistically reliable impact of order of testing on any cognitive measure with the exception of the second trial of the Motor Inhibition task (t (61) = 2.21, $p < .05$). Further investigation of the impact of order of testing on this task revealed that the order effect was only statistically reliable within the ADHD group, such that children with ADHD who started in the utilization behavior room committed significantly more errors than ADHD children who started in the computer testing room. Order of testing did not reliably influence levels of utilization behavior (t (61) = -.03, ns).

Attention and Inhibition

All participants were administered a continuous performance test to assess group differences in attention and concentration. As expected, children with ADHD overall displayed significantly more difficulty on the continuous performance task than did control children (F (4, 58) = 3.5, $p < .05$). Children with ADHD made more errors of omission (missed responses) than did controls (t (61) = -3.05, $p < .01$) and their performance was considerably more variable (t (61) = -3.24, $p < .01$), indicating problems with maintaining attention over the duration of the task. The groups did not significantly differ in overall number of commission errors (responding erroneously to an "X"; t (61) = -.07, ns), however, when numbers of commission errors were considered taking into account the number of missed responses, children with ADHD had a higher percentage of commissions per total responses (t (61) = -3.36, $p < .01$). When task performance was analyzed removing the effects of intelligence, overall intellectual ability was not found to be significantly associated with performance on the CPT task.

Utilization Behavior

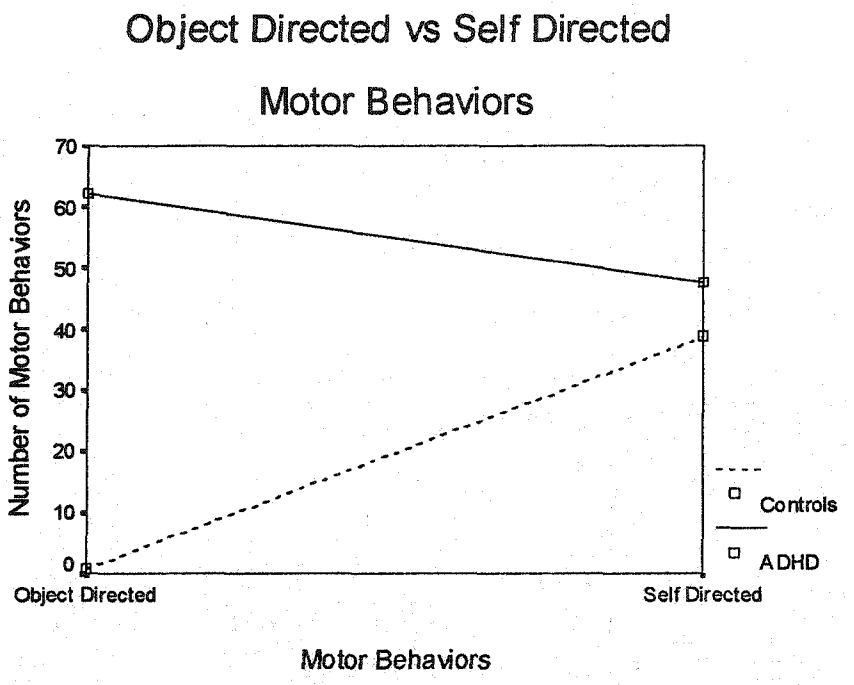
To explore the typology of physical overactivity in ADHD, a number of different dimensions of motor behavior, across a variety of testing conditions were examined. All analyses were first run with intelligence as a covariate, to statistically control or equate groups on level of intellectual ability. As intellectual ability was not found to be statistically related to any of the measures, nor did covariance of intelligence alter the pattern of results, analyses reported were completed without intelligence as a covariate in an attempt to improve the statistical power of these analyses.

To address concerns that object utilization may be a result of the participants' misunderstanding the purpose of objects placed around the table, levels of utilization behavior were analyzed under incidental (no instructions) and instructional (instructions not to touch the objects) conditions. Using independent samples t-tests, results indicated that equivalent levels of utilization behavior occurred when children were given instructions not to touch the objects as when they were not given any instructions regarding the objects (t (61) = -1.22, ns). This pattern held true for both the control (t (29) = .68, ns) and ADHD (t (30) = -.92, ns) samples. There were equivalent numbers of children with oppositional/defiant behaviors in the "instruction" and "no instruction" conditions as rated by parents and teachers, respectively (t (46) = .736, ns; t (42) - .382, ns).

To explore the nature of motor behaviors observed within the testing situation, behavioral ratings of object-related behaviors (toying and utilization behavior) and self-directed motor behaviors (self-touching) were subject to repeated measures analysis of variance. There was one within-subjects factor (motor behavior: utilization or self-touching) and one between-subjects factor (group). Analyses revealed a very different pattern of results between ADHD and control participants (see Figure 2), and a statistically reliable interaction between motor behaviors and group membership (F (1, 60) = 9.70, $p < .01$). Additional analyses of individual types of motor behaviors revealed that children with ADHD (M = 62.34, SD = 82.37) demonstrated significantly higher levels of object utilization than did controls (M = .68, SD = 1.83; t (61) = 4.12, $p < .001$), yet equivalent levels of self-touching behaviors (M ADHD = 47.5, SD = 25.94; M

Controls = 38.73, SD = 26.89; t (61) = -1.31, ns). This argues against a theory of general overactivity as the etiology of utilization behavior.

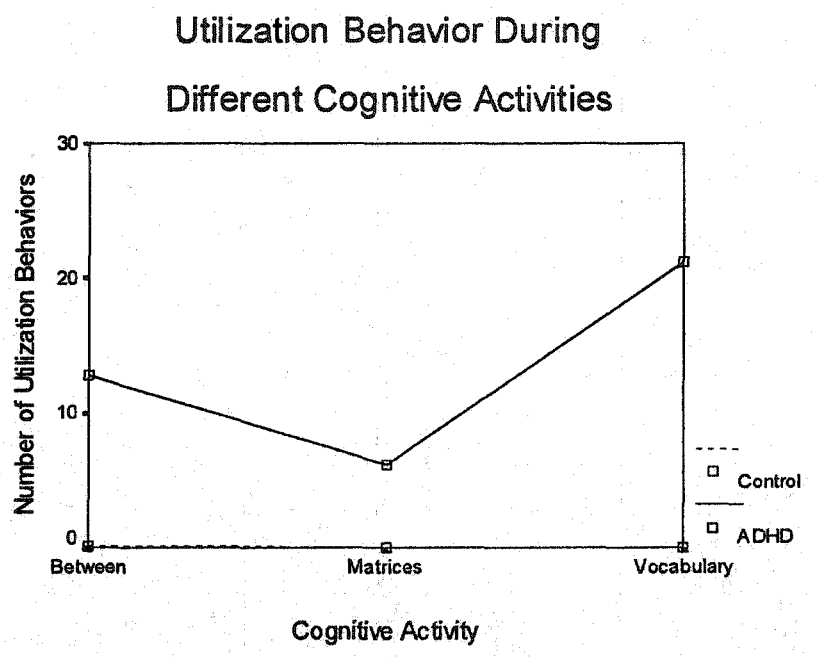
Figure 2 Types of Motor Behaviors



Analysis of levels of utilization behavior during various cognitive tasks also revealed a statistically reliable interaction between group membership and utilization behavior (F (2, 60) = 8.1, p < .001). There was a statistically reliable group effect such that children with ADHD exhibited significantly more utilization behaviors (F (2, 60) = 13.00, p < .001). Further exploration of the data revealed that control children were equally unlikely to use objects either doing verbal, visual, or between task conditions (M Between = .16, SD = .45; M Ravens = 0, SD = 0, M Vocabulary = 0, SD = .17). In contrast, children with ADHD where much more likely to utilize objects during the verbal task (M Vocabulary = 21.18, SD = 30.69) than during a visual task of equivalent

cognitive demand (M Ravens = 6.22, SD = 19.14; t (31) = 3.58, p < .001 – see Figure 3). The ADHD sample was also more likely to utilize objects between tasks than during the visual task (M =12.81, SD = 17.43, t (31) = 2.16, p <.05). Children within the ADHD sample exhibited a marginally significant difference in levels of self-touching versus utilization behavior (t (31) = .054, ns).

Figure 3 Utilization Behavior During Cognitive Tasks



Given the very low levels of utilization behavior demonstrated by children in the control sample, investigations into other dimensions of utilization behavior were conducted using data from the only ADHD sample. Results of paired sample t-tests indicated that children with ADHD were much more likely to utilize objects that were in their line of vision (M = 62.34, SD = 83.27) compared with objects that they were aware of which were not directly in sight (M = 4.75, SD = 9.04, t (31) = 4.17, p < .001). Utilization behavior was seen more often in response to objects that were familiar (M =

53.72, SD = 77.43) versus those that were unfamiliar (M = 11.69, SD = 21.97, t (31) = 3.23, p < .01). Finally, children with ADHD demonstrated significantly higher levels of "utilization behavior" (Complex Toying and True Utilization Behavior; M = 48.22, SD = 63.06) than mere fiddling with objects (Toying; M = 17.19, SD = 37.92, t (31) = 3.05, p < .01; see Figures 4 through 6).

Figure 4 Dimensions of Utilization Behavior - Location

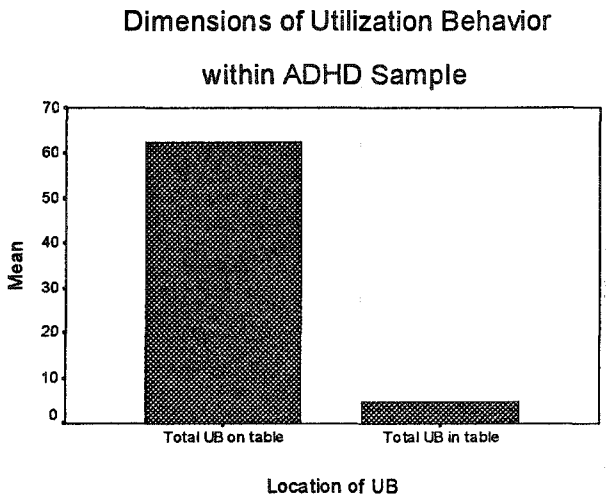


Figure 5 Dimensions of Utilization Behavior – Type of Object

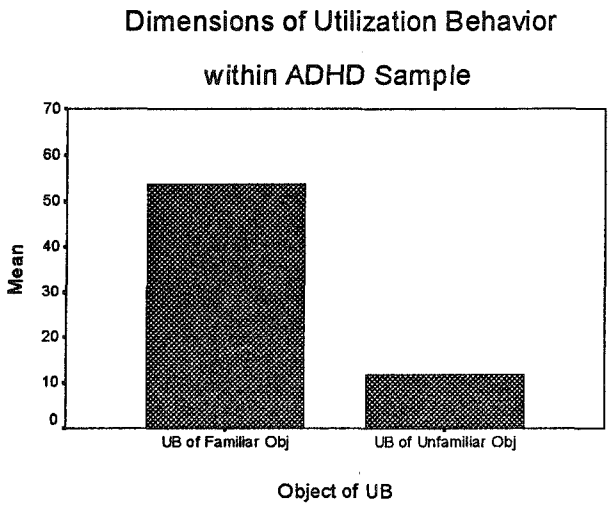
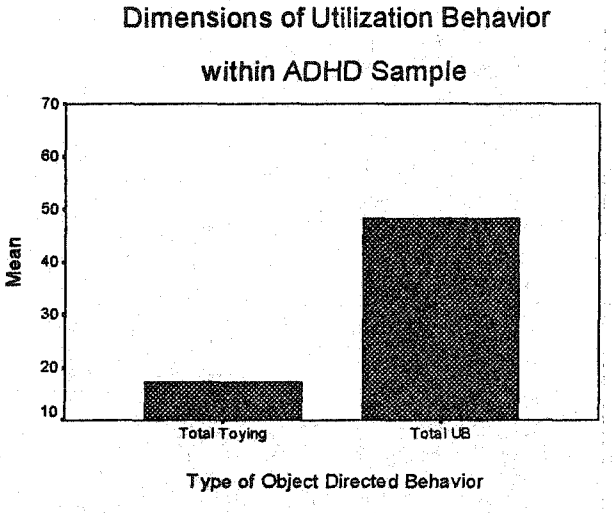


Figure 6 Dimensions of Utilization Behavior – Type of Behavior



Association of Utilization Behavior with Demographic Variables

To explore the relation between physical overactivity as measured in this study and severity of ADHD symptomatology, Pearson Product Moment correlations were obtained between motor behaviors recorded in the laboratory and numbers of hyperactive and inattentive symptoms reported by parents during the structured clinical interview. Within the ADHD sample, total utilization behavior was significantly correlated with number of hyperactive symptoms (r (26) =.47, $p < .05$) yet not with number of inattentive symptoms (r (26) =.14, ns). Further investigations of this relationship revealed that utilization behavior (Complex Toying + True Utilization Behavior) was significantly related to number of hyperactive symptoms (r (26) =.44, $p < .05$) whereas mere fiddling

with objects (Toying) was not (r (26) =.3, ns). Self-touching behaviors were not significantly associated with either hyperactive (r (26) =-.02, ns) or inattentive symptoms (r (26) =.04, ns). Children with ADHD and oppositional/defiant behaviors were significantly more likely to utilize objects than ADHD children without oppositional/ defiant behaviors ($t(25) = -2.611$, $p < .05$).

Motor abilities dependent on the medial motor system

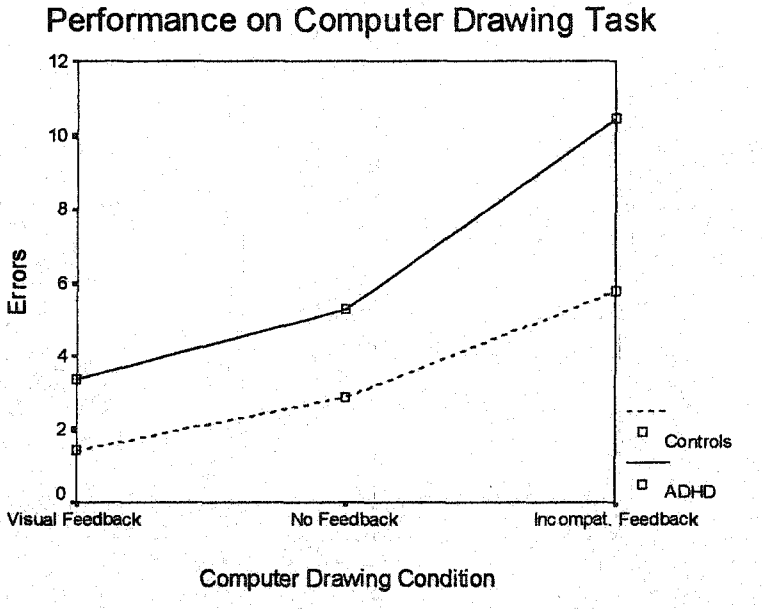
To explore medial motor abilities in children with ADHD, the present study investigated group differences on a number of different measures associated with the functioning of the medial motor system. Three different aspects of medial motor function were explored, including motor self-monitoring, motor learning/sequencing, and motor inhibition. Using analysis of covariance, it was again determined that covarying out intelligence did not alter any patterns in the findings, nor was intellectual ability significantly related to performance on any of the motor tasks. Therefore, to increase statistical power, the covariate was dropped from all reported analyses.

Motor self-monitoring and control were investigated utilizing three distinct drawing tasks; the Computer Drawing, Stirling Drawing, and Mirror Drawing Tasks. Scores on each measure were submitted to repeated-measures analyses of variance with one within subjects factor (task; errors within each condition) and one between-subjects factor (group).

Analysis of performance on the Computer Drawing Task revealed that there was no statistically reliable difference in performance in either sample when children were required to draw using either the keyboard or joystick. Therefore, to simplify the analyses scores were combined over these two conditions to yield 3 summary scores, 1)

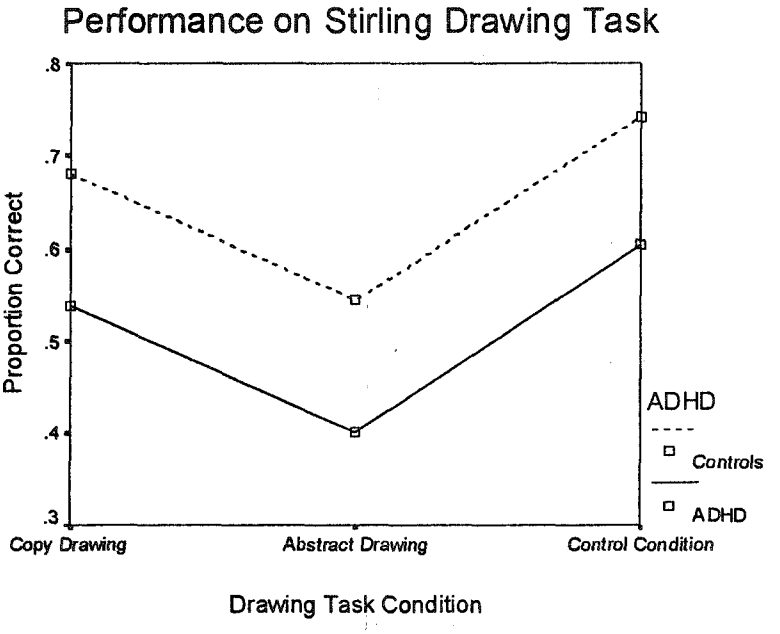
errors when drawing with visual feedback, 2) errors when drawing with no feedback, and 3) errors when drawing with incompatible feedback. The results revealed that children with ADHD overall displayed more difficulty on all three conditions of the task yielding a statistically reliable effect of group ($F(1, 60) = 4.06$, $p < .05$), and that these results were not a result of difficulties with memory for the shapes (control condition, $t(61) = 1.36$, ns). Control and ADHD participants displayed a different pattern of performance, as revealed by a significant interaction effect ($F(2, 60) = 3.94$, $p < .05$). All children experienced more difficulty on the "no feedback" and "incompatible feedback" conditions when compared with the "visual feedback" condition (see Figure 7), though children with ADHD were significantly more impacted than controls by incompatible feedback.

Figure 7 Medial Motor Abilities – Computer Drawing



Analysis of performance on the Stirling Drawing Task revealed a similar pattern of results. Children with ADHD displayed more difficulty on all conditions of this measure yielding a statistically reliable group effect ($F = 10.09$, $p < .01$). However, on this task the pattern of results between control and ADHD participants was very similar and there was no significant interaction effect (see Figure 8). Children within both samples experienced more difficulty on the first two conditions (drawing computer generated figures or abstract designs with no visual feedback) than on the final control condition (drawing abstract designs with visual feedback), yielding a statistically reliable effect of condition (F (2, 60) = 14.03, $p < .001$).

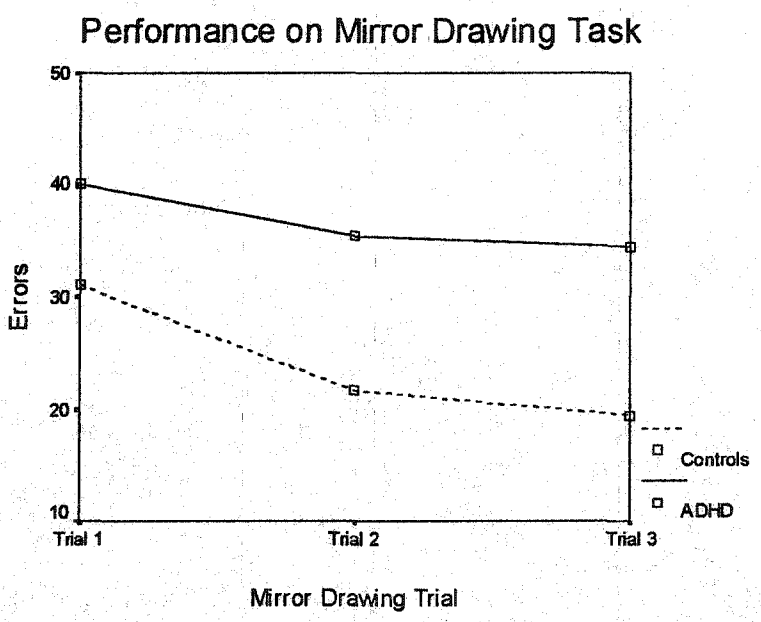
Figure 8 Medial Motor Abilities – Stirling Drawing



Similarly, analysis of performance across the first three trials of the mirror drawing task revealed statistically reliable effects for condition (F (2, 59) = 17.10, $p <$

.001) and for group (F (1, 60) = 11.30, $p < .001$). Children with ADHD overall made significantly more errors when required to draw in the mirror than did controls, and also displayed more difficulty under the control condition where they were required to draw outside of the mirror (t (60) = -3.04, $p < .05$). Although the interaction effect did not reach statistical significance, there was a trend indicating a different pattern of performance in ADHD and control samples (F (2, 59) = 2.67, $p = .07$). As seen in Figure 9, children within the ADHD sample demonstrated a slower pattern of improvement over the first three trials of the mirror drawing task. These differences did not appear to be due to children with ADHD rushing through the task; there was no reliable difference in total drawing time between the ADHD and control samples (t (2, 56)= .197, ns).

Figure 9 Medial Motor Abilities – Mirror Drawing



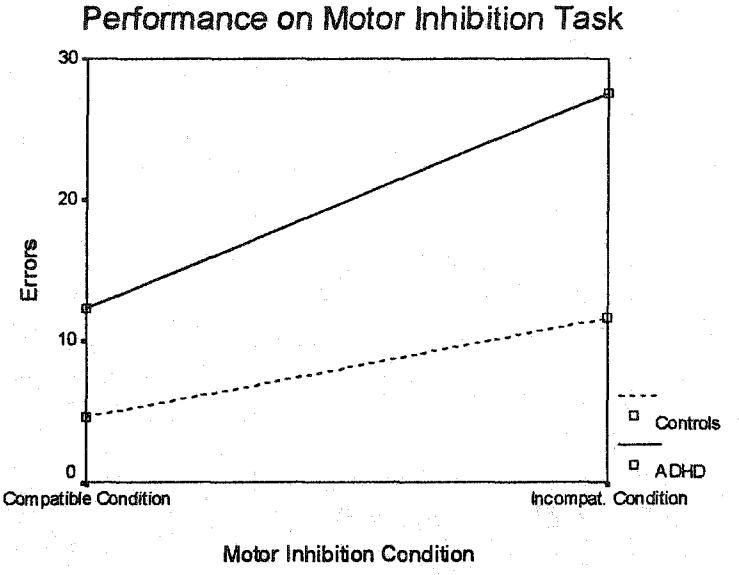
Motor Learning and Sequencing

Motor learning and sequencing ability were investigated using the Kimura box. Children with ADHD overall made significantly more errors on this task (F (1, 61) = 15.10, p < .001) than did controls with both their dominant and non-dominant hands. Observations of children while performing the task suggested that weaknesses with motor sequencing appeared to be due to true difficulty with the task rather than a result of errors due to impulsive responding.

Motor Inhibition

Scores from the Motor Inhibition task were also submitted to repeated measures analysis of variance, with one within-subjects factor (task; errors in the compatible or incompatible conditions) and one between-subjects factor (group). Given the significant effect of counterbalancing (described above), results were considered after covarying out the impact of counterbalance condition. Analyses revealed a differential pattern of results between ADHD and control participants (see Figure 10), with a statistically reliable interaction between condition and group (F (1, 54) = 12.26, p < .01). Additional analyses of each individual condition revealed that although in general both groups performed better on the compatible than the incompatible portion of the task, the ADHD group made disproportionately more errors in the incompatible condition (M ADHD = 27.55, SD = 16.85; M Controls = 11.62, SD = 11.62).

Figure 10 Medial Motor Abilities – Motor Inhibition



Relation of Medial Motor Abilities to Utilization Behavior

To explore the relation between medial motor abilities and utilization behavior, a principal components analysis (PCA) was performed on those aspects of each motor task related to functioning of the medial motor system. The specific measures that were included in this PCA were: the first two conditions of the Stirling Drawing Task, the "no visual feedback" and "incompatible feedback" conditions of the Computer Drawing Task, total errors for the Kimura Box, and total errors for the Mirror Drawing Task. Using the criteria of eigenvalues greater than 1, the PCA extracted 1 well-defined factor which accounted for 49% of the overall variance (see Table 5). Factor scores for individual participants were then correlated with total levels of utilization behavior, revealing a significant relationship between the two (r (61) =.44, p <.01).

Table 5

Principal Components Matrix/Medial Motor Abilities

Task/Condition	Component
Stirling Task Copying Drawings (no visual feedback)	-.708
Stirling Task Abstract Drawings (no visual feedback)	-.635
Computer Drawing (no visual feedback)	.731
Computer Drawing (incompatible feedback)	.775
Kimura Box Errors	.576
Mirror Drawing Errors	.759

A PCA was also performed on those aspects of the motor tasks not thought to be as dependent on the medial motor system. The variables that were included were: the Control (third) Condition for the Stirling Drawing Task, the "visual feedback" condition of the Computer Drawing Task, the Compatible Condition of the Motor Inhibition Task, and the Control Condition for the Mirror Drawing Task. Using eigenvalues >1 the PCA extracted 1 well-defined factor that accounted for 45% of the overall variance (see Table 6). In this case factor scores for individual participants were not significantly related to total levels of utilization behavior (r (55) =.25, ns).

Table 6

Principal Components Matrix/Lateral Motor Abilities

Task/Condition	Component
Stirling Task Copying Drawings (visual feedback)	-.831
Computer Drawing (visual feedback)	.847
Motor Inhibition Task (compatible Condition)	.527
Mirror Control	.329

Given that the distribution of scores for both medial motor problems and utilization behavior appeared to be highly skewed, the data was also analyzed using nonparametric techniques. The sample was divided such that all participants with medial motor factor scores above a value of 0 were designated as having "motor problems" (M = -.04, SD = 1). Similarly all individuals with utilization behavior scores above 10 (maximum levels of utilization behavior seen in the control sample) were designated as

"utilizers." Data exploration using cross-tabulation indicated that the majority of individuals who were "utilizers" displayed medial motor problems (70%). In addition, most individuals who were not utilizers did not display medial motor difficulties (82%; χ^2 (62) = 13.551, p < .001; See Table 7).

Table 7

Comparison of Utilization Behavior and Motor Problems

	Utilizer	Not Utilizer
Motor Problems	70%	18%
No Motor Problems	30%	82%

Discussion

The goal of the present study was to investigate physical overactivity (hyperactivity) in children with ADHD. To date most research has focused on symptoms of ADHD such as inattention and impulsivity, and the motor aspects of hyperactivity have been less studied. Because inappropriate and intrusive motor behaviors are a cardinal symptom of ADHD, a primary objective of this investigation was to provide a better understanding of typology and etiology of hyperactivity in this prevalent childhood condition. Given theories that children with ADHD may be less controlled by internally represented information and more so by external circumstances (Barkley, 1997b) and evidence that children with ADHD manifest dysfunction in prefrontal striatal circuits (Casey et al., 1997), it was hypothesized that certain aspects of hyperactivity in ADHD may constitute a "utilization behavior syndrome."

In investigating utilization behavior in this population this study first addressed concerns regarding previous utilization behavior paradigms (L'hermitte, 1983), in particular that the mere presence of the objects in the testing environment could have created an implicit expectation that the objects are to be used (Shallice et al., 1989). To

address this issue an "instruction condition" (in which instructions not to use the objects were provided) and a "no instruction condition" were compared. Results indicated that instructional set or expectation did not significantly influence the presence of utilization behavior. This pattern was true for both the control and ADHD samples. This corroborates that utilization behavior seen in this study did not simply reflect a misconception by participants regarding intended use of the objects.

Overall, the present study revealed that high levels of utilization behavior characterize physical overactivity in children with ADHD. Children with ADHD utilized objects within their environment much more frequently than did children within the community comparison group. Indeed the majority of children within the control sample completely ignored the objects around them. Closer examination of utilization behavior within the ADHD sample revealed that these children were much more likely to truly "utilize" objects than to fiddle aimlessly with them. This provides support that object-directed behaviors seen in children with ADHD appear to reflect a true "utilization behavior syndrome" rather than just simply fidgeting as a result of heightened activity levels. Further corroboration was provided through exploration of self-directed motor behaviours, which revealed that children with ADHD and control children were equally likely to demonstrate self-touching behaviors. This argues against explanations that children with ADHD are touching more objects simply because they are more active and touching everything around them.

Interestingly, levels of utilization behavior within the ADHD sample were significantly and specifically correlated with the severity of hyperactive symptomatology as reported by parents. In contrast, self-touching behaviors and fiddling with objects

(toying) were not. Utilization behavior was not significantly related to levels of inattention, indicating that object utilization appears to be a behavior specifically associated with the hyperactive component of the behavioral phenotype in ADHD, as measured by behavioral ratings by parents. Further exploration of the data revealed that significant utilization of objects occurred in only a portion of the ADHD sample. More specifically, utilization behavior was significantly associated with parental and teacher ratings of oppositional behavior within ADHD children. Further, a diagnosis of Oppositional Defiant Disorder (ODD) based on the DICA was significantly associated with utilization behavior within the ADHD sample. Research indicates that ADHD and ODD are frequently comorbid (40-60%) and that this combination of difficulties could constitute a distinct and more severe subtype of ADHD (Tannock, 1998). However, children with ADHD and ODD did not differ on any of the other cognitive measures administered during the study. Therefore, it is also possible that children with ADHD, who exhibit high levels of hyperactivity characterized by utilization behavior (i.e., more intrusive and inappropriate hyperactive behavior) may be perceived by their teachers and parents as more defiant and oppositional.

In addition, this study compared levels of utilization behavior in response to familiar versus unfamiliar objects, to explore theories that utilization behavior may specifically result from disinhibition/release of parietal/lateral motor schemata as a result of dysfunction within frontal control systems (Shallice et al., 1989). If this were true, one would expect to see utilization behavior in response to objects that are familiar (for which an individual has developed a schemata), yet not in response to unfamiliar objects. Results indicated that utilization behavior was more common in response to objects that

were familiar versus those that were unfamiliar, providing some support for theories regarding disinhibition of lateral motor schemata (Shallice et al., 1989). Again this supports the contention that utilization behavior in ADHD may reflect a more specific syndrome, rather than generally heightened activity levels towards all aspects of their environment.

Finally, exploration of utilization behavior within the ADHD sample across different conditions revealed that, as predicted, utilization behavior was highly dependent on the visual system. Utilization behavior occurred significantly more often in response to objects that were in sight (on the table) compared with those objects that children were aware of yet that were out of their line of sight. This clearly supports that visual stimulation appears to elicit utilization behavior in this population. In addition, utilization behavior was more was much more common during verbal tasks than during tasks of equivalent cognitive demand where the visual system was engaged. This pattern also provides corroboration for the hypothesis that utilization behavior may result from disinhibition of a more primitive (visual) lateral motor system (Gazzaniga, Ivry, & Mangun, 1998). That is, when the lateral motor system is engaged in a cognitive (visual) task utilization behavior is much less likely to occur. In contrast, when the lateral motor system is not occupied (during a verbal task) utilization of objects in the environment is much more likely. Consistent with previous studies of the utilization behavior syndrome, utilization behavior also frequently occurred during the breaks between tasks (Shallice et al., 1989).

To further explore the hypothesis that aspects of physical overactivity in ADHD, including utilization behavior, could be a result of disinhibition of a lateral (visual) motor

system participants also completed a number of motor tasks. These tasks were selected and developed to assess motor abilities thought to be dependent on medial (frontal) motor system, which was hypothesized to be functioning less efficiently in children with ADHD. Medial motor tasks included those that assessed abilities such as motor self-monitoring, learning/sequencing, and inhibition (Goldberg, 1985). Most tasks also included control components that were thought to be less influenced by the above-described medial motor abilities and more dependent on basic motor function/control.

Motor self-monitoring or the ability to maintain an internal motor representation is an ability that has been purported to depend on the functioning of the medial motor system (Goldberg, 1985). In the current study, children with ADHD displayed significant difficulty on all aspects of the motor self-monitoring tasks, including those control components not thought to depend as heavily on medial motor pathways.

More specifically, the first two conditions of the Stirling Drawing Task (Stirling, 1999) required children to draw geometric figures and then to choose from a selection of very similar drawings, generated by the computer, the exact one that they had created. There was no visual feedback present during these first two conditions and performance therefore required the ability to maintain an internal representation based on proprioceptive feedback. Children with ADHD performed significantly more poorly than controls during both these motor-monitoring conditions. The Computer Drawing task (Mlakar et al., 1994) also assessed the ability to maintain an internal motor representation. Under "no visual feedback conditions" and "incompatible feedback conditions" children were required to maintain a representation of the geometric figure they were reproducing in the absence of feedback or in the presence of visual

interference, respectively. Performance of children with ADHD on these tasks was again significantly weaker than that of controls. Finally, a comparison of performance across the first three trials of the Mirror Drawing Task revealed that children with ADHD made significantly more errors than control children when tracing a figure in the presence of visual interference (reversed feedback from the mirror). There was a trend suggesting that children with ADHD demonstrated a slower pattern of improvement (shallower learning curve) on the task than did controls. However, is important to note that children with ADHD also performed more poorly on the control conditions of these three measures, which were not thought to be associated with motor self-monitoring ability. It is possible that either the control conditions did place demands on motor self-monitoring and control that had not been expected, or that children with ADHD also have some difficulty in aspects of motor control subserved by the lateral system. Observations of children did not suggest that difficulties were a result of impulsive responding.

Motor learning/sequencing and some aspects of motor inhibition are also hypothesized to be associated with the functioning of the medial motor system (Goldberg, 1985). Results indicated that children with ADHD demonstrated significantly more difficulty with motor learning and sequencing than did control children, as assessed by their ability to learn and correctly reproduce a motor sequence using the Kimura Box (Kimura, 1977). Observation of performance suggested true difficulties with motor learning/sequencing as opposed to errors due to impulsivity or inattention to the task. Children with ADHD also demonstrated notable difficulty on the Motor Inhibition Task (Casey et al., 1997). The incompatible condition of the Motor Inhibition task assessed the ability to respond to stimuli using incompatible motor mappings, and hence to inhibit

a competing and prepotent motor response based on an internalized rule. Although children within both samples committed more errors on the incompatible versus compatible condition of the task, children with ADHD made disproportionately more errors during the incompatible condition. This suggests that children with ADHD display difficulties with resisting an automatic response when required to respond in accordance with a new rule that is incompatible with visual feedback (Casey et al., 1997).

Overall, children with ADHD demonstrated notable difficulties on measures of motor self-monitoring, motor learning/sequencing, and motor inhibition; three aspects of motor skill thought to be dependent on the medial motor system. However, the ADHD sample also displayed difficulty on the control conditions of each task suggesting that the control tasks may have demanded some degree of motor self-monitoring. It also could be that children with ADHD demonstrated motor problems beyond those strictly limited to the medial motor system. Observations of the children during testing did not suggest that group differences were a result of lack of effort, impulsivity, or problems with motivation. One noted limitation of this study was the lack of inclusion of established measures of more basic motor function, such as motor speed and dexterity. However, other studies that have addressed these skills have found normal performance on such basic motor tasks not thought to be dependent on internal controls or frontal motor abilities (Barkley et al., 1992; Grodzinsky & Diamond, 1992; Shue & Douglas, 1992).

Finally, this study also attempted to address the hypothesis that an imbalance between medial and lateral motor systems could lead to utilization behavior (Goldberg, 1985). This was explored through investigations of whether utilization behavior seen in children with ADHD appeared to be associated with dysfunction within the medial motor

system. Tasks that were theoretically related to functioning of the medial motor system were subject to PCA yielding one well-defined factor (medial motor factor), which was significantly correlated with levels of utilization behavior. Those measures less dependent on the medial motor system (control conditions) were also subject to PCA yielding one factor (external motor factor), which was not significantly related to utilization behavior. To further explore the relationship between utilization behavior and medial motor problems, participants were categorized as either having motor problems or not (based on their score on the medial motor measures) and as either being "object utilizers" or not (based on the levels of utilization behavior demonstrated). Results indicated that the majority of individuals who demonstrated utilization behavior also displayed medial motor problems. Further, most of those individuals who did not utilize objects did not demonstrate medial motor problems.

In general, Goldberg's (1985) hypotheses regarding the utilization behavior syndrome were supported. According to Goldberg's theory, an imbalance between proposed medial and lateral motor systems would lead to environmentally driven responding (including utilization behavior). More specifically, dysfunction within the medial motor system would result in disinhibition of the lateral motor system, and high levels of visually driven responding reflected in behaviors such as object utilization. In the present study, children with ADHD did display evidence of dysfunction within the medial motor system, evident through impaired performance on a number of motor tasks thought to depend on medial motor abilities. In addition, there were several lines of evidence supporting disinhibition of the lateral motor system within this population. First, utilization behavior was much more prominent in response to objects that were in

children's line of sight versus objects that they were aware of which were out of sight. This supports a strong visual component to utilization behavior, as utilization of non-seen objects would require some mental representation and invoke the medial system. Second, utilization behavior was much more likely to occur during non-visual activities (verbal activities or between tasks) than during visual activities when the lateral system was engaged. Clearly disinhibition of the lateral system would not be possible when the visual system is occupied (Goldberg, 1985), as has been demonstrated in earlier studies of the utilization behavior syndrome (Shallice et al., 1989). Finally, utilization behavior appeared to be significantly associated with the dysfunction within the medial motor system, as measured by a statistically reliable relationship between performance on tasks thought to be dependent on medial motor abilities and levels of utilization behavior. However, one clear limitation of the present study was the lack of inclusion of more measures associated with the lateral/external motor system, to provide evidence of divergent validity.

The current investigation also provided important information regarding the nature of physical overactivity within ADHD. First, findings indicated that hyperactivity in ADHD does appear to be characterized by high levels of true utilization behavior, and that utilization behavior is not merely a byproduct of heightened activity levels. Therefore, many of the inappropriate and intrusive behaviors (distractibility and impulsivity) seen in children with ADHD are likely a result of this "utilization behavior syndrome" rather than intentionally or motivationally driven. Second, results indicated that utilization behavior was clearly associated with the level of hyperactivity in children with ADHD. Not all children within the ADHD sample demonstrated utilization

behavior, but rather these behaviors appeared to be associated with a more severe form of the disorder as defined by parental ratings of hyperactive behaviors. In particular, utilization behavior was significantly associated with ratings of oppositional and defiant behavior by parents and teachers. It is possible that ADHD comorbid with ODD consitutes a distinct and more severe subcategory of ADHD (Tannock, 1998). On the other hand, it is possible that children with higher levels of hyperactivity and intrusive/impulsive behaviors (including utilization behavior) are simply perceived as more oppositional by those who work with them. For example, they would appear to simply disregard direct requests to not touch things in their environment, a behavior that would likely be seen as oppositional.

The present study also provided important information regarding theoretical conceputalizations of the primary neurocognitive deficit in ADHD. Although there have been several theories regarding the core deficit in ADHD, many contemporary researchers have conceptualized the central problem to be a deficit in behavioral inhibition (Barkley, 1997a; Barkley, 1997b; Pennington & Ozonoff, 1996; Quay, 1988; Schachar et al., 1993; Schachar et al., 1995a). One of the more comprehensive models of ADHD is offered by Barkley (1997b), who proposes that a primary deficit behavioral inhibition leads to secondary impairments in four executive neuropsychological abilities that are dependent upon behavioral inhibition for their execution. Dysfunction within the four executive abilities lead to problems with motor control/fluency/syntax and for children with ADHD to be less well controlled by internally represented information and more so by external stimuli.

Although the current study was not entirely inconsistent with Barkley's (1997b) theory of ADHD, there is a more parsimonious explanation for the behavioral symptomatology seen in this population; externalizing symptomatology within ADHD, including hyperactivity, distractibility, and impulsivity may be the direct result of an imbalance between medial and lateral motor systems, as a result of dysfunction within the medial motor system. In other words, the neurocognitive deficit in ADHD may directly reflect a disruption of frontal motor connections leading to difficulties with motor control and motor inhibition (Niedermeyer & Naidu, 1997). This hypothesis is consistent with previous studies that have documented impaired "frontal motor abilities" in children with ADHD (Grodzinsky & Diamond, 1992; Shue & Douglas, 1992) and with recent neuroimaging data suggesting that ADHD may reflect frontal-motor uncoupling as a result of dysfunction within frontal-striatal circuits (Casey, in press; Casey, 1997 #15; Hynd et al., 1991a; Niedermeyer & Naidu, 1997). In other words, ADHD may be better conceptualized as reflecting a primary disorder of motor control, rather than a disorder of behavioral inhibition or executive dysfunction (Barkley, 1997b).

Finally, the present investigation also provided information that may be helpful to consider in working with and educating children with ADHD. First, if children with ADHD truly manifest an imbalance between medial and lateral motor abilities, this population would be expected to be highly dependent on salient environmental cues for guiding their responding. In particular, visual stimuli would be very engaging for these children. This has clear implications for instruction in the classroom whereby these children may learn more effectively via visual and hands-on activities, as opposed to verbal instruction. In addition, low stimulation environments with few visual stimuli may

be more effective in reducing distractibility and impulsivity. Finally, the intrusive and inappropriate motor behavior seen in ADHD (particularly excessive touching and fiddling with objects in the environment) is most likely unintentional, and should be managed sensitively.

Conclusions and Future Directions

Although the present study helped to elucidate the etiology and typology of hyperactivity within the ADHD population, there are still many unanswered questions that could be addressed in future research.

First, one clear limitation of this study was the issue of ecological validity. Children were tested in a novel laboratory setting by two examiners with whom they were not familiar. Observations of utilization behavior within the childrens' natural environments, where they feel more comfortable in and familiar with their surroundings, would provide useful information on the prevalence and significance of these behaviors in their daily lives.

Second, not all children with ADHD exhibited utilization behavior. Utilization behavior appeared to be both associated with the severity of hyperactivity and the presence of oppositional and defiant behaviors. Given the limitations of this study it was not possible to determine whether children with ADHD and oppositional defiant disorder constitute a distinct and more severe subtype of ADHD, or whether high levels of hyperactivity and utilization behavior are perceived more negatively by those individuals who interact with these children. During the current study, it was not possible to determine whether children with pure ODD (not co-occurring with ADHD) also exhibit aspects of utilization behavior. In addition observations of children within the ADHD

sample suggested that some children appeared to be "motorically" hyperactive and some children appeared to be more "verbally" hyperactive (e.g., talking incessantly, yet not exhibiting high levels of fidgety or squirmy behaviors). It would be interesting to compare levels of utilization behavior across children who manifest their overactivity in verbal versus motoric domains. These issues warrant further study.

Third, a more clear understanding of those motor tasks used to assess the functioning of medial and lateral motor systems is warranted. This lack of construct validity for the measures that were used could be addressed through the use of neuroimaging studies to confirm their association with either medial or lateral motor pathways. It would also be helpful to investigate the performance of children with ADHD on motor measures thought to be dependent on the external/lateral motor system.

Finally, the investigation of the relationship between medial motor abilities and utilization behavior, and various forms of inhibition associated with distinct frontal-striatal circuits (Casey, in press), would provide more specific information on the relation of behavioral inhibition to frontal motor abilities and utilization behavior within the ADHD population.

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Appendix I

Picture of Kimura Box Stimuli