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Sense of Time, Inhibition and Working Memory in College-Aged Students

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This study investigated the concepts of sense of time, inhibition and working memory in college-aged students. Barkley's Theory of Attention-Deficit/Hyperactivity Disorder (ADHD) (1997a) identifies hierarchical relationships between inhibition, working memory and sense of time. However, other research has hypothesized that sense of time is not related to working memory, but is instead related to deficits in an internal, cognitive clock. Based on these competing theories, this experiment tested the hypothesis that sense of time is related to inhibition above and beyond working memory. Fifty college-age participants completed tasks measuring inhibition, verbal working memory, visuospatial working memory and sense of time. Two facets of sense of time were measured. Participants completed a time reproduction task; however, because time reproduction tasks confound sense of time with a motor response, participants also completed a time discrimination task. Finally, self-report measures were used to assess for symptoms of ADHD, trait anxiety and the Behavioral Inhibition System.

Inhibition was not related to time reproduction or time discrimination. In addition, time reproduction was not related to working memory, ADHD or trait anxiety. However, time discrimination was related to working memory, self-report symptoms of ADHD and trait anxiety. Subsequent analyses showed that visuospatial working memory predicted above and beyond verbal working memory. When tested in a stepwise fashion, self-report measures of ADHD and trait anxiety both predicted significant variance in time discrimination ability above and beyond working memory. Further analyses showed that, although participants were able to solve medium level time discrimination items using working memory, as the level of difficulty increased and exceeded the capacity of working memory, participants were forced to rely more on their sense of time. The results of this study provide evidence that symptoms of ADHD and anxiety are related to "purer" deficits in sense of time as related to an internal clock.

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CHAPTER 1

THE PROBLEM

This paper will explore the concepts of sense of time, inhibition and working memory in college-aged students. Barkley's (1997) Unifying Theory of ADHD identifies inhibition as the central deficit in persons diagnosed with ADHD. This deficit in inhibition impacts four executive functions, one of which is the ability to hold information in working memory. According to Barkley's theory, this deficit in working memory is believed to result in an impaired in sense of time, particularly as it relates to the ability to accurately judge and reproduce time intervals. Others have argued that these deficits in sense of time are not related to working memory, but are instead related to deficits in an internal, cognitive clock (Smith, Taylor, Rogers, Newman, & Rubia, 2002). This paper will also explore Gray's conceptualization of the behavioral inhibition and behavioral activation systems. Although these systems have been related to other measures of inhibition, no research has yet attempted to link these concepts to sense of time. Many studies have investigated and confirmed that children with ADHD demonstrate difficulty with sense of time, particularly on tasks that require the reproduction of a time interval. However, there is less evidence documenting the relationship between inhibition and sense of time in adults. This investigation will test the hypothesis that inhibition is related to sense of time; it will also test the hypothesis that working memory is related to sense of time. If both hypotheses are supported, this project will test the hypothesis that inhibition contributes to sense of time above and beyond working memory. This investigation will also test the hypothesis that Gray's Behavioral Inhibition System is related to sense of time.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Diagnostic Criteria and Impact of ADHD

Attention Deficit Hyperactivity Disorder is a characterized by developmentally inappropriate levels of inattention, hyperactivity and/or impulsivity (American Psychiatric Association, 2000). Inattentive symptoms include difficulty paying attention to details, difficulty sustaining attention, or not listening when spoken to directly. Hyperactive symptoms include fidgeting with hands, often leaving a seat in a classroom, as well as running or climbing excessively. Impulsive symptoms include blurting out answers, difficulty waiting one's turn and often interrupting or intruding (American Psychiatric Association, 2000). In order for a diagnosis to be made, some difficulties must be noted before age seven and impairment must be demonstrated in at least two settings; this helps to rule out situational problems as a cause of the disorder.

Attention-Deficit/Hyperactivity Disorder is one of the most common childhood disorders. Prevalence estimates for ADHD vary from 3-7% (American Psychiatric Association, 2000), to as wide as 2-18% depending on who is asked what and how the information is blended (Rowland, Lesesnse & Abramowitz, 2002). In childhood, males are diagnosed with ADHD approximately four times more often than females (Rowland, Lesesnse & Abramowitz, 2002). This may reflect a true difference, but may also be influenced by the fact that male children are more likely to demonstrate the externalizing symptoms that draw the attention and subsequent diagnosis of ADHD.

Adults with ADHD

Although ADHD is grouped in the "Disorders Usually First Diagnosed in Infancy, Childhood, or Adolescence" section of the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM-IV-TR), ADHD is now recognized as a chronic, lifelong condition that often persists into adolescence and adulthood (Barkley, Fischer, Smallish, & Fletcher, 2002; Wilens, Biederman & Spencer, 2002). Barkley (1998) reports that 50-70% of children with ADHD continue to report symptoms into adulthood, while others have reported that 31-66% of persons continue to report symptoms into adulthood (Gittelman, Mannuzza, Shenker, & Bonagura, 1985; Mannuzza, Klein, Bonagura, Malloy, & Addali, 1991). Many studies report different remission rates depending on whether symptomatic or functional remission (which includes impairment) is reported (Biederman, Mick & Faraone, 2000). Higher remission rates seem to be associated with symptomatic remission.

A 2006 study by Kessler et al. attempted to estimate the prevalence of adult ADHD using a subsample of 18-44 year old 3,199 adults from the National Comorbidity Survey Replication, a nationally representative survey. Lay-administered interviews were used to estimate a variety of DSM-IV disorders and blind follow-up clinical interviews were used to secure accurate diagnoses. The clinical interviews used the Adult ADHD Clinical Diagnostic Scale version 1.2, a semistructured interview that includes the ADHD rating scale. The results of the study estimated the prevalence of adult ADHD at 4.4%. The authors identified this prevalence rate as conservative.

Studies have investigated the psychological and neuropsychological characteristics of adults with ADHD. A meta-analysis of intellectual functioning by

Bridgett and Walker (2006) found that 1,031 adults with ADHD scored lower than 928 controls on the Wechsler Adult Intelligence Scale. However, this group difference was small (an average of 2.94 points) and did not seem clinically significant. This result was also limited by a number of moderators which suggested that only a subset of adults with ADHD (such as those with other comorbid disorders) are likely to experience lower intelligence. Dige and Wik (2005) investigated adults with ADHD using neuropsychological measures sensitive to frontal lobe dysfunction and working memory deficits. They were able to correctly identify 81% of adults with ADHD using memory tests. Adults with ADHD had difficulty with verbal dual-task memory as measured by the auditory Consonant Trigram test, visual short-term memory as measured by the Benton Visual Retention Test and verbal short-term memory as measured by Digit Span Backward (but not Digit Span Forward). These studies indicate that adults with ADHD do not differ significantly from controls on general measures of intelligence, but they may differ on measures of executive functioning or working memory.

Causes of ADHD

Although the causes of ADHD are currently unknown, many people now suspect that ADHD is a neuropsychiatric disorder linked to the frontal lobe, basal ganglia and cerebellum (International Consensus Statement on ADHD, 2002). Deficits in the frontal lobe of the brain may be related to some of the inattention symptoms and self-regulation deficits that are common in ADHD (Voeller, 2004). Within the frontal lobe, many people suspect dysregulation of the prefrontal cortex (Clarke, Heussler & Kohn, 2005) which is responsible for the regulation of cognitive activities that permit self-control and goal-directed behavior; these cognitive activities are known as executive functions. The basal ganglia and cerebellum are regions of the brain that play an important role in the control of movement. Therefore, abnormalities in these brain regions may be directly related to some of the symptoms of hyperactivity that persons with ADHD experience. Much of the research on causes of ADHD has also focused on neurotransmitters, specifically, dopamine and norepinepherine (Voeller, 2004). Dopamine plays an important role in goal-directed behavior, learning, and working memory, while norepinepherine is involved in helping to maintain alertness and attention. Genetics seem to play a role in the development of ADHD, as do pregnancy and delivery complications; particularly if the brain of the infant is deprived of oxygen (Biederman & Faraone, 2005). Finally, a brain injury to the frontal lobe can also result in ADHD-like symptoms.

Overall, these neuropsychological abnormalities seem to result in deficits in executive functioning, particularly on tasks which require fast and accurate processing of information or slow and careful processing of information (Tannock, 2002). Barkley's theory of ADHD describes these deficits in executive functioning in greater detail.

Inhibition and ADHD

Barkley's theory of ADHD characterizes ADHD as a disorder of impaired behavioral inhibition; this central deficit in inhibition disrupts executive functioning and results in impaired motor control, fluency and syntax (Barkley, 1997a). A representation of Barkley's theory of ADHD is attached in Appendix A. The term behavioral inhibition subsumes three interconnected processes: the ability to inhibit prepotent (or predominant) responses, the ability to stop an ongoing response, and interference control (Barkley, 1997a). According to Barkley's theory, the symptoms of hyperactivity, impulsivity and inattention that characterize ADHD result from difficulties inhibiting inappropriate behaviors and following internal instructions (Barkley, 1997a). This underlying deficit impacts four executive functions that depend on inhibition to function properly. Executive functions are cognitive actions that impact self-regulation by preventing distractions and promoting goal-directed behavior (through the use of hindsight, forethought, motivation, and interference control). Inhibition impacts these executive functions because the first executive act must be the inhibition of responding (Barkley, 1997a).

The first executive function that is impacted by response inhibition is the capacity to hold information in working memory and use that information to direct a response. According to Barkley's theory, inhibition aids working memory by allowing for a delay in response to an event; working memory is activated during this delay. Inhibition also aids working memory by providing interference control (Barkley, 2000). These deficits in working memory result in secondary deficits in sense of time, particularly in the ability to accurately judge and reproduce time intervals. This is because the time interval must be maintained in working memory (Barkley, Koplowitz, Anderson & McMurray, 1997). According to Barkley's theory of ADHD (1997), working memory has retrospective (hindsight) and prospective (forethought) functions that allow people to engage in goal-directed behavior and complete tasks in a timely manner. This involves the relation of past events to future events, essentially, "remembering to do so" (Barkley, 1997a). Deficits in inhibition disrupt this ability to refer backward and forward in time.

Working memory is the theoretical system underlying the maintenance of task-relevant information during the performance of a cognitive task (Shah & Miyake, 1999). Working memory is more than a conceptual storage space; it is an active workspace where information is actively processed. Shah and Miyake's *Models of Working Memory* (1999) offers a discussion of the different issues in working memory including how information is represented in working memory, the limitations of working memory and the impact of attentional processes on working memory. According to Baddeley and Logie (1999), verbal information is maintained in a phonological loop, whereas visuospatial information is held in a visuospatial sketchpad. These two storage systems are controlled by a central executive (Baddeley, 2003). In accordance with this model, it seems that many authors agree that working memory is not a single unified concept, but rather a group of several domain-specific subsystems (Kintsch, Healy, Hegarty, Pennington & Salthouse, 1999). Kintsch et al. (1999) discuss the limitations of working memory. Although it seems that working memory has a limited capacity, there are different theories as to the source of these limitations (including limits imposed by processing speed, interference control and inhibition). Finally, working memory appears to be closely related to attentional processes (Kintsch et al., 1999). Attentional processes help select which information is encoded and attended to in working memory. Working memory capacity can also be viewed as a function of attentional processes (Kintsch et al., 1999).

The next executive function Barkley's theory describes as impaired is self-regulation of emotional and motivational states. This executive function allows people to modulate their level of arousal, act in socially appropriate ways and demonstrate emotional self-control. Self-regulation also provides intrinsic motivation and thus, persistence toward goals (Barkley, 2000). The third executive function that is impaired in persons with ADHD is the internalization of speech. Internalized speech allows children to privately question themselves, follow directions and self-reflect on skills (Barkley, 1997a). The final executive function that is impaired involves the ability to dissect observed behaviors, separate them into parts and reassemble the parts to form new actions; this is known as reconstitution. Reconstitution helps people to work towards goals creatively and flexibly (Barkley, 1997a).

These four executive functions, along with response inhibition, impact motor control (Barkley, 1997a). Within the domain of motor control, persons with ADHD demonstrate deficits in timing, novelty of response, and complexity of response (Barkley, 1997a; Fuster, 1995). It seems that persons with ADHD have difficulty with the rapid execution of complex, coordinated sequences of movements. For example, this may result in difficulties in writing or drawing. Finally, persons with ADHD demonstrate deficits in behavioral flexibility (Barkley, 1997a).

Barkley's 1997 unifying theory of ADHD addresses many different issues. This paper will focus on examining the proposed deficits in sense of time that, according to Barkley's theory, should follow from deficits in working memory.

Gray's Theory of Behavioral Inhibition and Behavioral Activation

Gray has proposed an alternate conceptualization of inhibition that may have relevance to this study. Gray proposed two dominant dimensions of personality: anxiety and impulsivity (Carver & White, 1994). Due to Gray's conceptualization of anxiety and impulsivity as enduring dimensions of personality, these concepts are determined to reflect personality traits. Gray postulated that anxiety is produced by activity in the Behavioral Inhibition System (BIS). The BIS is an aversive motivational system in the brain that inhibits behavior that may lead to pain, punishment, or other negative outcomes

(Gray, 1978). This system is related to negative affect and is responsible for such emotions as anxiety, frustration, and sadness (Gray, 1978). Greater BIS sensitivity should result in a greater anxiety. The Behavioral Activation System is an appetitive motivational system that activates behavior in response to cues for reward or escape from punishment (Gray, 1987). The BAS is related to positive affect and is responsible for feelings such as hope, elation, and happiness (Carver & White, 1993). Greater BAS sensitivity should be associated with impulsivity (Matthys, van Goozen, de Vries, Cohen-Kettenis, & van Engeland, 1998).

The Behavioral Inhibition/Behavioral Activation model describes individuals with ADHD as having an underresponsive BIS and an overactive BAS (Sergeant, Geurts, Huijbregts, Scjeres, & Oosterlaan, 2003). However, to be consistent with Barkley's theory, this study will focus on the Behavioral Inhibition System rather than a combination of the BIS and BAS. Avila and Parcet (2001) provided some evidence that Gray's Behavioral Inhibition system is related to inhibition. However, the BIS has not yet been linked to measurements of sense of time. Research shows that persons with ADHD experience difficulty on tasks measuring sense of time; therefore, individuals characterized by an underactive BIS should also experience difficulty on tasks measuring sense of time. Anxious individuals are usually described as having an overactive BIS and an underactive BAS (Shackman et al., 2006). Shackman et al. (2006) were also able to show that these individuals exhibited higher levels of anxiety and that this anxiety seemed to disrupt visuospatial working memory. If visuospatial working memory is related to prospective memory and sense of time, then anxious individuals should also demonstrate impairment on tests measuring sense of time.

Sense of Time and ADHD

Time perception is an adaptive function that allows people to predict and anticipate events (Toplak, Rucklidge, Hetherington, John, & Tannock, 2003). Sense of time can be connected to many of the core deficits in ADHD; impulsivity can even be defined as a pattern of temporally inadequate behavior in which future consequences are not contemplated (Smith et al., 2002). Interestingly, the areas of the brain that are responsible for time perception are the same areas that are impaired in ADHD. These areas include the prefrontal cortex, the basal ganglia, and the cerebellum (Harrington, Haaland, & Knight, 1998). Iconic memory seems to be most important in the processing of time intervals that are shorter than one second. Working memory seems to be most important for intervals that range from one second to 20 or 30 seconds. Timing tasks that exceed 20-30 seconds seem to be more dependent on long-term memory (Bauermeister et al., 2005).

Some researchers have tried to relate biological clocks to sense of time. These models revolve mainly around biological clocks that control circadian rhythms (Zakay & Block, 1997). Most of these models are based around the idea that a temperature sensitive biological clock controls sense of time. However, these models have not been proven to be consistent. Many cognitive variables (especially attentional processes) can have a large impact on sense of time; therefore, many researchers prefer cognitive models of time.

Many cognitive timing models are based around the idea of an internal clock or pacemaker (Church, 1984) that produces pulses at a constant rate. The attentional-gate model (Block & Zakay, 2006) is one such model. A representation of the attentional-gate model has been attached in Appendix B. According to this model, when a person begins attending to time, as opposed to other external events, a gate opens and the pulses from the pacemaker are allowed to flow to a switch. When an interval begins, the switch opens and allows the pulse stream to flow through to a cognitive counter (or accumulator). The cognitive counter counts up and keeps a running total using working memory. When a signal indicates that that a timing period has ended, the switch closes and the pulse total is transformed and stored in a reference memory. A representation of a target interval (for example, in minutes and seconds) can be encoded in reference memory directly from long-term memory (Block & Zakay, 2006). The idea of long-term reference memory seems to be similar to Ericsson and Kintsch's (1995) concept of long-term working memory, a memory that has rapid reference to something that has happened before. Finally, the attentional-gate model includes a cognitive comparator which may make a response by comparing the current pulse total in working memory with pulse totals in reference memory.

In contrast to Barkley's theory of ADHD, Cognitive models of time usually attribute impairments in sense of time to the pacemaker, not to working memory. Block and Zakay (2006) argue that the internal clock can be influenced by arousal, such that increased arousal results in the production of more pulses. However, Church (1984) has argued that the pacemaker can also be influenced by drugs, diet and stress.

The attentional-gate model specifies that the gate opens in accordance with how much attention a person is paying to time. This attentional-gate is controlled by executive functions. If a person is focusing their attention more on some external event, there are less attentional processes available to open the gate. Also, if a person is engaging in an easy external task, rather than a difficult external task, more attentional processes can be devoted to opening the attentional gate. As a result, the attentional-gate model predicts that time judgments will be longer for easier tasks and shorter for harder tasks (Zakay & Block, 1997).

Timing tasks are divided into two types, retrospective tasks and prospective tasks. Different cognitive processes underlie these two different types of tasks (Zakay & Block, 1997). During a retrospective timing task, participants are not told beforehand that they will be asked to estimate or reproduce a time interval. Persons with ADHD are not expected to demonstrate difficulties on this type of task because it does not place many demands on inhibition, attentional processes and executive functioning; it is instead based on memory storage and retrieval (Zakay, 1992).

During a prospective timing task, participants are alerted that they will be expected to attend to an upcoming interval and that a response will be expected of them. The attention-gate model applies to prospective time judgments, because it involves a person actively attending to time. This type of memory is related to executive functioning. In a 2001 experiment, Kerns and Price documented significant differences in prospective memory between children with ADHD and a control group. The experiment involved a video game that required the children to drive a car, remember to press a button to check the gas in a car, and fill the gas when it was low. Children with ADHD ran out of gas more often that controls. In this experiment, prospective memory performance correlated significantly with the Connors' Parent Rating Scale.

Prospective memory tasks are often divided into four types, verbal estimation, motor production, motor reproduction and time discrimination tasks (Zakay & Block, 1997). The first type of prospective timing task is verbal estimation. During this type of task, a time interval is presented non-verbally (e.g. turning on a light for a specified time interval); after the interval ends, participants are asked to verbally report how long the interval lasted. The second type of prospective timing task is motor production. Here, participants are verbally told a duration (e.g. “20 seconds”) and asked to reproduce it nonverbally (e.g. by turning on a light for 20 seconds). The third type of prospective task is motor reproduction. Here, a time interval is presented nonverbally (e.g. by turning on a light for a specified interval) and participants are asked to reproduce the time interval through a nonverbal means (e.g. turning on a light for the same interval). Children with ADHD seem to find time reproduction to be the most difficult because it demands a greater allocation of attentional processes to temporal processing and makes larger demands on working memory and interference control (Zakay, 1992). The time reproduction task also requires a motor response, making it still more difficult for persons with ADHD. However, this makes it is more difficult to determine the reason why persons with ADHD have difficulty with this task.

The fourth type of prospective sense of time task is a time discrimination task (Zakay & Block, 1997). Using this method, participants are asked to compare durations. This type of task represents a purer measure of sense of time because it eliminates variance due to motor difficulties. Smith et al. (2002) argue that these types of tasks can help establish whether children with ADHD demonstrate a “pure” deficit in sense of time related to an internal pacemaker.

Studies of Sense of Time

Many studies have confirmed deficits in sense of time in children with ADHD. A 1997 study by Barkley, Koplowitz, Anderson, and McMurray investigated sense of time in children ages 6-14. The ADHD group consisted of 12 children while the control group consisted of 26 children. The children in the ADHD group were referred to a university medical center for a controlled evaluation of methylphenidate. Participants were eligible for the ADHD group based on a structured diagnostic interview with a licensed child clinical psychologist as well as elevated scores on the Achenbach Behavior Checklist. The study used a time reproduction task wherein a red light bulb would light for a designated time interval. Following the time interval, participants were asked to turn on a flashlight for the same amount of time that the red light bulb had been lit. The study asked children to reproduce intervals ranging from 12 to 60 seconds. Each child made 4 attempts to reproduce each time interval. A distraction (such as a jack-in-the-box figure popping up) occurred on two of the four trials. Children with ADHD were significantly less accurate than controls; they were also significantly less accurate when distracted (particularly when trying to reproduce time intervals of 12, 24 and 36 seconds). Control children were not impacted by the distractions. Children with ADHD overreproduced short intervals but underreproduced longer intervals. Both groups became less accurate as the time interval increased.

The article also discussed a second study performed on the 12 children with ADHD. The purpose of this study was to evaluate any possible effects of stimulant medication on the time reproductions of the ADHD children. The study showed that the administration of methylphenidate did not increase the ability of children with ADHD to accurately reproduce time intervals. The researchers were surprised by this finding because methylphenidate has been shown to improve the working memory of children with ADHD and reduce deviations from the norm on other cognitive measures (Tannock, 1995).

A 2005 study by Bauermeister et al. investigated time estimation and time reproduction in Hispanic children ages 7-11. The study consisted of a group of 33 children diagnosed with the combined type of ADHD, a group of 21 children diagnosed with the inattentive type of ADHD and a control group of 25 children. Children taking stimulant medications were excluded from the study. All children completed a time estimation task which asked them to verbally estimate how long a visual stimulus (a flashlight) was turned on. Each child completed two trials of each interval presented in two different sequences (6, 13, 25, 10, 33, and 18 seconds and 33, 6, 18, 10, 13, and 25 seconds). These sequences were determined randomly. The children were also asked to complete a time reproduction task that utilized the same intervals, but in two different sequences. In this task, the children were asked to use a flashlight to reproduce the interval presented by the examiner. The main effect of group was not significant in the time estimation task. On the time reproduction task, the effect of group was significant. Both ADHD groups made greater errors than the control group; the combined type and inattentive type ADHD groups did not differ significantly. Again, the effect of duration was also significant indicating that the errors made by the children in both groups tended to increase in magnitude (regardless of direction) as the time intervals increased in duration. However, this finding does not seem to be surprising and will not be reported in future experiments cited in this paper. Finally, the group x duration interaction was not significant. The researchers concluded that these results indicated that children with ADHD did not have difficulty accurately detecting durations (as in the time estimation task). They demonstrated difficulty when using information in working memory to guide a motor response (as in the time reproduction task).

A regression analysis showed that measures of nonverbal memory (which this paper will refer to as visuospatial memory) and inhibition (specifically, interference control) made significant contributions to the time reproduction task. Visuospatial memory was measured by the Simon Task, a circular device with four different colored keys that light up and emit different tones which must be reproduced in correct sequence. Interference control was measured by the Stroop Color and Word Test, a test commonly used to measure the inhibitory functions of interference control. These results supported Barkley's (1997) theory of ADHD by showing that inhibition and working memory contribute to sense of time as measured by time reproduction tasks. However, one of the main drawbacks of this study was that time intervals were manually presented by the examiner. This makes it difficult to precisely present durations and record responses. A more precise timing task may have been able to detect additional differences.

A 2000 study by West et al. investigated sense of time in children (ages 6-12) using a computerized time reproduction task called the Time Perception Application (Timetest; Barkley, University of Massachusetts Medical Center, 1998). This computerized program allowed the researchers to administer and record responses, particularly reproduction responses, much more precisely. Two groups were used in this study, an ADHD group (consisting of 14 children diagnosed as predominantly inattentive and 30 children diagnosed as combined type) and a control group (which consisted of 44 age-matched children). All of the children in the ADHD group were diagnosed by a pediatrician as meeting DSM-IV criteria for ADHD (with no comorbid diagnoses). Participants were unmedicated for at least 20 hours prior to testing.

The Time Perception Application allowed the researchers to administer both visual and auditory stimuli. The test consisted of four subtests (visual reproduction, visual reproduction with distractors, auditory reproduction and auditory reproduction with distractors). Each subtest consisted of four trials at each of five durations (the researchers chose 0.5, 2, 3, 4, and 5 seconds), presented at random. During the visual trials, a computerized light bulb was lit up for a specified duration. Sometimes, a visual distraction (a bug or bee moving across the screen) appeared during the presentation of the stimulus. Participants were instructed to hold down the space bar in order to light another light bulb on the computer screen for the same duration (no distractions were used during the reproducing phase). During the auditory trials, a tone was emitted. Auditory distractions (such as a train whistle or swinging golf club) were employed during some of the trials. Participants are instructed to hold down the space bar to produce a tone of an equivalent duration.

On the visual time reproduction task, children with ADHD made significantly larger errors than controls (regardless of ADHD subtype and the presence of distractions). The children with ADHD were more likely to overreproduce shorter time intervals (0.5 seconds and 2 seconds) and underreproduce longer time intervals (3, 4 and 6 seconds). This finding was similar to the results of Barkley et al., 1997; however, the range of the time intervals was different (0.5-6.0 seconds in this study, 12-60 seconds in Barkley et al.'s 1997 study). Children in the ADHD-Combined and ADHD-Inattentive groups were similarly impaired; however, there were only 14 children in the inattentive group, so it is possible that some differences were not able to be detected by this experiment. On the auditory reproduction task, the researchers did not find any between group differences; both groups consistently underreproduced the durations. The researchers pointed out that the failure of the distractors to distinguish between the ADHD and control groups surprisingly contradicted the results of Barkley et al.'s 1997 study. They thought that this difference may have been due to the computer-generated distractors used in their study (which did not require the participants to look away from the screen) as opposed to the Jack-In-The-Box operated by the researcher in Barkley et al.'s 1997 study. The researchers also believed that the shortness of their time intervals may have given the children (averaging an age of 10 years) some difficulty. This study provided more evidence that children with ADHD present with deficits in sense of time (as measured by time reproduction tasks); however, this deficit may only apply to visual stimuli as opposed to both auditory and visual stimuli.

McInerney and Kerns (2003) investigated whether deficits on time reproduction tasks reflect a deficit in sense of time or whether these deficits are confounded by motivational deficits (which might mean that these deficits are related to self-regulation rather than working memory). The study compared 30 ADHD (Combined Type) children and 30 matched controls ages 6-13. The controls were matched by gender and age. Children with ADHD were selected based on methods similar to those described in previous studies. Children were required to discontinue medication 24 hours prior to testing.

The groups completed a computerized “light bulb game” involving time reproduction tasks. Although the researchers did not specify, the description of the task they used seems to indicate that they used a program very similar to the Time Perception Application described in the previous experiment. The experiment utilized two trials at each of six target durations (3, 5, 6, 9, 12, and 17 seconds), presented in random order. Participants were asked to click their mouse button in order to light their light bulb for the same amount of time as the other bulb had been lit. However, the researchers also added a motivational variable. In one condition, the examiners rewarded the children with positive sham feedback (in which an animal walked across the computer screen and congratulated the child on their performance, regardless of how well they performed on the task) and the possibility of earning a gift if they scored extremely high (the prize was placed so that it was clearly in sight); this condition was identified as the enhanced condition. This enhanced condition was compared to a control condition where no reinforcement was provided. Each child played both versions of the game. As a secondary goal, the researchers also investigated working memory and behavioral inhibition and how these constructs related to sense of time as predicted by Barkley’s theory.

In the regular light bulb game, children in the ADHD group made significantly larger time reproduction errors than controls did; the group x duration interaction was not significant. In general, children in the ADHD group tended to over-reproduce shorter time intervals and under-reproduce longer time intervals. In the enhanced condition, there was again a significant effect of group; however, in this case there was also an interaction effect. Specifically, as the target duration increased, children with ADHD made relatively larger errors than control children did. The results also showed that children with ADHD made significantly fewer errors in the enhanced condition versus the regular condition. Control children did not perform differently on the two tasks. This showed that a more engaging task resulted in improved performance in the ADHD group, but this performance still did not approach that of the control group.

Children in the control group performed significantly better on four working memory tasks (Digit Span Backward, Children's Size Ordering Task, Children's Paced Auditory Serial Addition Task, and Sentence Span Measure). These four measures were combined to create an overall working memory variable. Children with ADHD also performed worse than controls on a Stop Signal task measuring behavioral inhibition.

In the regular condition, a regression analysis showed that both working memory and inhibition significantly predicted total time reproduction error after controlling for age. Group membership also predicted time reproduction abilities after statistically controlling for working memory and response inhibition. In the enhanced condition, working memory and inhibition significantly predicted total time reproduction error after controlling for age. However, group membership did not predict time reproduction errors after controlling for inhibition and working memory. The researchers thought that the results in the enhanced condition were most consistent with Barkley's theory which stipulates that deficits in sense of time are secondary to deficits in inhibition and working memory; therefore, group differences should disappear when these factors are controlled. The researchers concluded that children with ADHD seem to have a deficit in time reproduction abilities but that these difficulties may be partially improved through motivation.

A 2001 study by Kerns, McInerney and Wilde investigated behavioral inhibition, working memory, attention, and time reproduction in children ages 6-13. The ADHD group consisted of 21 children previously diagnosed with the combined type of ADHD. These children were asked to discontinue medication 24 hours prior to the study. The control group consisted of 21 children matched by gender and age. The researchers used a computerized light bulb game which was similar to the previous light bulb games described. Each child completed 2 trials at each of 6 durations (3, 5, 6, 9, 12, and 17 seconds). The researchers also collected information on working memory (as measured by a working memory game and a Self-Ordered Pointing Test), behavioral inhibition (as measured by a visual Go/No Go task and the Golden version of the Stroop Task) and attention (as measured by the Conners' Continuous Performance task (CPT)).

The researchers found a significant main effect for group and a significant duration x group interaction indicating that children with ADHD made significantly larger errors in comparison to controls and that these errors became significantly larger as the duration increased. Children with ADHD were found to perform significantly differently from controls on measures of inhibition (specifically, they made more omission errors on the Go/No Go task), attention, and time reproduction, but, interestingly, not on measures of working memory (the findings approached significance at $p=.07$).

The researchers also explored the relationships between working memory, inhibition and attention. Total time reproduction error was correlated with errors of commission on the Go/No Go task and the measure of impulsivity/inhibition (β) on the Conners' CPT. The measures of working memory were not correlated with the time reproduction task; this finding was inconsistent with Barkley's (1997) theory. The researchers thought that this might have been due to the fact that both of the measures of working memory utilized in this study consisted of maintenance tasks (in which information is maintained after a delay) as opposed to manipulation tasks (in which information needs to be reorganized or reordered).

Smith et al. (2002) also investigated sense of time in children aged 7-14 by comparing children diagnosed with ADHD and controls on time discrimination, time reproduction and time estimation tasks. The clinical group consisted of 22 children diagnosed with ADHD (impulsive or combined types) or hyperkinetic disorder using DSM-IV or ICD-10 criteria as well as cutoff scores on a parental questionnaire and the Conners' Abbreviated Questionnaire for parents. All children discontinued medication 24 hours prior to testing. The control group consisted of 22 children who scored below the cut-offs.

The experiment consisted of a time discrimination task in which a green circle appeared on the left side of the screen for a designated duration, followed by a red circle appearing on the right side of the screen. Each circle was accompanied by a tone which lasted for the same duration as the visual stimulus. The duration of one of the circles was fixed at 1000ms while the other was varied. The participants were then asked which circle lasted longer. Each error resulted in a 15ms increase in the comparison duration (this increased the difference between the two stimuli so that the participant would be able to detect the difference more easily); each correct response reduced the difference between the two durations (this made the difference between the stimuli more difficult to detect). After 6 reversals were made or 20 trials had been completed the researchers computed a threshold level. This experiment also included a time reproduction task. This task utilized a computer program in which ‘enemy’ planets moved towards the subject; after 12 seconds, planet Earth arrived and subjects were instructed to land on the planet by pressing a key. Next, the participants were told to land on the target planet earth again, but all of the ‘enemy’ planets were disguised to look like planet earth, so the subject had to correctly remember how long it took to travel to planet earth (spaces were inserted so that participants were not able to simply count the number of planets). Participants completed 10 trials of this task. Participants also completed a 5 second time reproduction task. This task consisted of a bomb exploding on the computer screen, after which, participants were instructed to hold a key down to activate a sprinkler system that would put the fire out if it was activated for exactly the same amount of time as they waited for the bomb to explode. Participants completed 10 trials. Finally, an interval of 10 seconds was presented and participants were asked to verbally estimate how long the interval lasted.

The study did find a group difference in the time discrimination task. The time intervals needed to be 50ms longer in order for children diagnosed with ADHD to be able to discriminate between intervals of different lengths. IQ scores and Digit Span scores were not correlated with this threshold. The study found no group differences on the 5 second time reproduction task or the 10 second verbal estimation task. There was a difference in the 12 second time reproduction task, but this difference dropped below significance after controlling for IQ and digit span scores. The initial difference on the time reproduction task led the researchers to conclude that time reproduction tasks do seem to load upon other process, such as working memory, besides an internal clock.

However, the researchers concluded that differences on the time discrimination task presented evidence of a pure time deficit in ADHD. This challenges the view that sense of time deficits in ADHD are found only on tasks containing a motor component.

A 2003 study by Toplak et al. investigated duration discrimination (which this paper will refer to as time discrimination) and duration estimation (which this paper will refer to as time reproduction) in children ages 6-12. The study compared a group of 50 control children to a group of 50 children with ADHD; however, 19 of the children in the ADHD group had comorbid reading difficulties, so this was considered a separate group, leaving 31 children in the ADHD group. Children with ADHD were diagnosed via the Parent Interview for Child Symptoms-IV (PICS-IV) and the Teacher Telephone Interview-IV (TTI).

The time discrimination task required participants to determine which of two intervals was the longest (with a fixed target of 400ms versus a comparison). The intervals were marked by brief tones at both the beginning and end of the intervals, but the interval itself was silent. The issue of filled versus unfilled intervals is controversial (Block, 1990) as this may make it more difficult for the respondents to attend to the interval. However, these authors chose to use unfilled intervals with the hope that it would minimize confounds due to ongoing processing of auditory stimuli. Participants were to indicate which of the two unmarked intervals they thought was longer. The comparison interval was always longer than the target interval; it was adjusted to be relatively longer or shorter depending on the accuracy of the participant’s responses. As a control, the researchers used a frequency discrimination task. Participants were asked to discriminate between a target frequency of 3000 Hz and a comparison frequency (which was adjusted to be slightly higher or lower depending on the accuracy of the participant's response). For their analysis, the researchers calculated the mean duration and frequency thresholds (the difference that could be discriminated from the target frequency with 80% accuracy). The time reproduction task used intervals of 400ms, 2000ms, and 6000ms. As in the previous task, the researchers used an initial boundary tone to set the beginning of each interval and a second boundary tone to mark the end of the interval. Respondents reproduced the interval by tapping the beginning and end of the interval. Dependent variables included the mean and standard deviation of the estimated duration for each of the three intervals.

Children with ADHD were less accurate than controls on the time discrimination task and displayed more intra-individual variability on the time reproduction task (at 2000 and 6000ms intervals). Children in the ADHD+RD group displayed less accurate performance on the time discrimination task. Children in the ADHD+RD group were significantly different at the 400 ms and 6000 ms intervals of the time reproduction task. Finally, children in the ADHD+RD group demonstrated more intra-individual variability at all three levels of the time reproduction task. As predicted, neither group demonstrated impairment on the frequency discrimination task.

Although there are many studies investigating sense of time in children with ADHD, there are fewer studies examining this topic in adolescents. However, Barkley has conducted an investigation of sense of time in adolescents that is similar to his study of sense of time in children. Barkley, Edwards, Laneri, Fletcher and Metevia investigated sense of time in adolescents (ages 12-19) diagnosed with ADHD/ODD and a control group (2001). This study followed 101 teens with ADHD (Combined Type)/ODD and 39 controls. ADHD was identified according to teacher and parent interviews as well as elevated scores on the Achenbach Child Behavior Checklist. Those teens taking psychiatric medications were asked not to take their medications on the day of testing.

Participants completed time estimation and time reproduction tasks. The time estimation task required participants to verbally estimate durations of 2, 4, 12, 15, 45, and 60 seconds. Two short durations were presented (2 and 4 seconds), two durations fell within the time span of working memory (12 and 15 seconds), and two intervals fell within the span of long-term memory (45 and 60 seconds). The administrator began each interval by saying that he was starting a stopwatch and ended the interval by saying that he was stopping the stopwatch. Two sets of intervals were administered; the durations were presented in ascending order in the first set and in mixed order in the second set. The time reproduction task utilized the same 12 intervals, presented in the same manner. Participants reproduced the time interval by telling the administrator when to stop and start the stopwatch. For both estimation and reproduction tasks, participants scores were rounded to the nearest second. The researchers also utilized the Conners Continuous Performance Test as a measure of vigilance and response inhibition. Digit Span Reversed was used as a measure of verbal working memory and the Simon game was used as a measure of visuospatial working memory.

Results indicated that adolescents with ADHD displayed greater impairments on time reproduction, but not on tasks requiring time estimation. The researchers concluded that adolescents with ADHD made greater errors on the time reproduction task because it placed greater demands on attention allocation and working memory. The results did not specify whether adolescents with ADHD were more likely to under-reproduce or overreproduce time durations, only that they made greater errors. The study also investigated differences in executive functioning and working memory. Results showed that the ADHD group scored higher on CPT inattention, but no differences were found for working memory and CPT inhibition. These results indicated that adolescents with ADHD may be able to perceive time accurately (as measured by verbally identifying time durations), but they demonstrate impairment when are asked to coordinate a motor response. The researchers did not test to see if measures of inhibition, inattention, or working memory were correlated with scores on either the time estimation or time reproduction tasks.

Toplak et al. also conducted their (2003) study on adolescents ages 13-16. The same groupings were used. There were 35 adolescents in the ADHD group, 24 in the ADHD+RD group, and 39 in the control group. Compared to controls, adolescents in the ADHD group did not differ on the time discrimination task or in mean estimated time reproductions. However, they did demonstrate significantly greater inter-individual variability on the time reproduction task at 2000ms and 6000ms. Adolescents in the ADHD+RD group did differ from controls on the time discrimination task. They also demonstrated significantly different time reproductions at 400ms, but not at 2000ms or 6000ms. Finally, adolescents in the ADHD+RD group demonstrated greater intra-individual variability on all three time reproduction tasks. As expected, adolescents in the ADHD and ADHD+RD group did not demonstrate impairments on the frequency discrimination task.

This study also conducted a regression analysis on the adolescent clinical sample (ADHD and ADHD+RD groups). Working memory measures (Digits Forward Standard

Score and Arithmetic Standard Score on the WISC-III) significantly predicted performance on the time discrimination task. This indicates that working memory may still be related to sense of time, even on tasks measuring a purer sense of time as related to an internal pacemaker. Estimated Full-Scale IQ and teacher reported hyperactivity/impulsivity (using the hyperactive/impulsive scale on the Conners' Teacher Report) predicted performance on the time reproduction task, but only at the 400ms interval. This appears to be the only study which has tested the correlation between hyperactivity/impulsivity, working memory and sense of time in adolescents.

Although there are many studies investigating sense of time in children and some studies of adolescents with ADHD, there seems to be a shortage of studies investigating sense of time in adults with ADHD. Barkley, Murphy and Bush (2001) investigated time estimation and reproduction in young adults aged 17-28. The experiment consisted of two groups, 104 adults with ADHD and 64 control adults. Participants with ADHD were recruited from referrals to a clinic specializing in ADHD and selected on the basis of elevated scores on the Adult ADHD Rating Scale (participants completed one copy describing current functioning and one copy describing childhood functioning). When reflecting on childhood symptoms of ADHD, the researchers asked participants to consider their behavior between the ages of 5 and 12 (based on evidence that the DSM-IV-TR criteria that some symptoms must occur before age 7 significantly reduces the reliability of diagnosis, Applegate et al., 1997). Following this screen, participants completed a diagnostic interview created for the experiment. Participants were asked to discontinue medication for 24 hours prior to testing.

The time estimation task required participants to verbally estimate durations of 2, 4, 12, 15, 45, and 60 seconds. The same 12 intervals were utilized in the time reproduction task. Durations were presented with a stopwatch in the same manner as Barkley, Edwards, Laneri, Fletcher and Metevia (2001). The ADHD group made larger time estimates than the control group (particularly at larger intervals such as 45 or 60 seconds); however, these differences became nonsignificant after controlling for IQ. On the time reproduction task, the ADHD group made shorter reproductions at durations of 15 and 60 seconds. They also made greater reproduction errors at 12, 45 and 60 seconds. These differences remained after controlling for IQ and comorbid diagnoses. The findings did not seem to be associated with gender or ADHD subtype. These results provide evidence that adults with ADHD demonstrate difficulties on tasks that require the reproduction of time intervals (but not on tasks requiring the estimation of time intervals). The researchers concluded that these findings support theoretical impairments in sense of time as a consequence of deficits in working memory resulting from impaired inhibition (in the form of interference control). However, although the researchers make the claim that impairments in sense of time result due to deficits in working memory and inhibition, the researchers did not directly assess inhibition or working memory and attempt to test the hypothesis that these variables should be correlated with sense of time. Thus, there is not currently any research exploring the relationship between inhibition, working memory and sense of time in adults.

Summary of Studies of Sense of Time

These studies provide evidence that there is a correlation between inhibition, working memory and tasks measuring sense of time in children. There is also some evidence supporting this link in adolescents. However, no research has attempted to directly establish a correlation between inhibition, working memory and sense of time in adults. There is little evidence that persons who have deficits in inhibition have difficulty with time estimation tasks. However, there is evidence that persons who have deficits in inhibition have more difficulty with time reproduction tasks. This could be because time reproduction tasks make substantially greater demands on interference control, working memory and motor control. Some studies have used time discrimination tasks to show that inhibition may be related to sense of time above and beyond deficits related to working memory. The following hypotheses outline how this investigation will examine these concepts in adults.

Hypotheses

This investigation will test the hypothesis that inhibition is related to sense of time in adults; it will also test the hypothesis that working memory is related to sense of time in adults. If both hypotheses are supported, this project will test whether inhibition contributes to sense of time above and beyond working memory. Finally, this investigation will test the hypotheses that clinical measures of ADHD, anxiety and the behavioral inhibition system are related to sense of time in adults.

CHAPTER 3

PROCEDURES

Participants

Fifty random participants were recruited from the undergraduate subject pool at Indiana University of Pennsylvania. Participants included 33 females (66%) and 17 males (34%). Of the participants, 78% identified as Caucasian/European-American, 18% identified as African-American, 2% identified as Latin American and 2% identified as Native American. Participants ranged in age from 18 to 29 (M = 19.36, SD = 1.91).

Measures

Go/No Go Task. In order to measure inhibition, a Go/No Go task was designed using Inquisit computer software. Participants were instructed to respond to some stimuli (the Go part of the task), but inhibit their response to other stimuli (the No Go portion of the task). The Go portion of the task forms a prepotent response habit that participants must inhibit during the No Go items. Specifically, participants were instructed to press the space bar, as quickly as possible, after every number that was not a 6 (this included the numbers 0-5 and the numbers 7-9). Participants were instructed not to press the space bar after the number 6. A random number generator within Inquisit was used to present random stimuli during each administration. In addition, the Go/No Go task was divided into 5 blocks that varied the pretrial pause (the pause before each stimuli was presented) between 250 and 500ms. A participant's score was determined by the total number of commission errors (pressing the space bar in response to a No Go item). Scores were calculated as a percentage of the total commission errors made out of the total number of commission opportunities. Higher percentages indicate a greater amount of commission errors.

This Go/No Go task was created for this project, so reliability estimates were examined. The administration of the Go/No Go task was broken up into 5 blocks, each separated by a 15 second pause. Although the overall percentage of commission errors was used in the analysis, commission percentage scores were also calculated for each of the five blocks. A correlation matrix of the five blocks of percentage of commission errors is presented in table 1. These five blocks were used to calculate a Cronbach's alpha of .82. This indicates good internal reliability.

Table 1.
Pearson Correlations Between Blocks of the Go/No Go Task

	B1	B2	B3	B4	B5
B1					
B2	.43**				
B3	.42**	.49**			
B4	.54**	.34*	.37**		
B5	.47**	.46**	.66**	.64**	

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Digit span. The Digit Span subtest from the Wechsler Memory Scale-III (WMS) was used as a measure of verbal working memory. Digit Span includes two parts, Digit Span Forward and Digit Span Backward. Digit Span Forward requires participants to repeat increasingly difficult digit spans in the same order that the evaluator has read them. Digit Span Backwards requires participants to repeat sequences of digits in reverse order. Digit Span Forward is designed to measure the maintenance aspects of verbal working memory while Digit Span Backwards is designed to tap the manipulation aspects of verbal working memory. Each participant was given two trials at each digit span length. The test was discontinued when participants responded incorrectly to both trials at a given digit span length. On both Digit Span Forward and Digit Span Backward, participants were given 1 point for each trial that they were able to reproduce correctly; their score for Digit Span consisted of the total number of correct trials. The split half reliability for digit span is reported to be .90 (Kaufman & Lichtenberger, 1999).

Spatial span. The Spatial Span subtest from the Wechsler Memory Scale-III (WMS) was used as a measure of visuospatial working memory. Like Digit Span, Spatial Span includes two parts, Spatial Span Forward and Spatial Span Backward. During Spatial Span Forward, the evaluator taps blocks on a 3-D grid in a sequence. The participant is asked to correctly tap the sequence in the same order. In Spatial Span Backwards, the evaluator again taps blocks in a sequence, but the participant is asked to tap the blocks in reverse order. Spatial Span Forward is designed to test the maintenance aspects of visuospatial working memory; Spatial Span Backwards is designed to examine the manipulation aspects of visuospatial working memory. Each participant was given two trials at each spatial span length. The test was discontinued when participants responded incorrectly to both trials at a given spatial span length. On both Spatial Span Forward and Spatial Span Backward, participants were given 1 point for each trial that they are able to reproduce correctly; their score for Spatial Span consisted of the total number of trials correctly reproduced. The internal reliability of spatial span is reported to be .79 (Wechsler, 1997).

Light Bulb Game (Time Reproduction Task). The Time Perception Application (Barkley, 1998) (referred to in this experiment as the Light Bulb Game) is a computer-administered, visual time reproduction task. The Light Blub Game was administered to measure participants' ability to accurately reproduce time intervals. During each trial, a visual stimulus (a light bulb) appeared "lit" on one side of the screen for the specified interval. Participants were then instructed to hold the space bar down for an equivalent interval to light another light bulb on the other side of the screen for the same interval. Durations of 2, 4, 6, 8, and 10 seconds were chosen for the task. The test included 4 trials at each of the 5 durations for a total of 20 randomly presented trials. Before beginning the 20 experimental trials, participants completed 3 practice reproductions.

Similar to the analysis performed by Barkley, Murphy & Bush (2001), the analysis of the Light Bulb Game included analyses of the absolute discrepancy and coefficient of accuracy scores. The absolute discrepancy score is the absolute value of the difference between the reproduced duration and presented duration. This score does not consider the direction of the error, simply how big the error was. For each participant, an absolute discrepancy score was calculated for each interval. However, the absolute discrepancy score for the 10 second interval was typically much larger than the absolute discrepancy score for the 2 second interval. Therefore, for this experiment, scores for each interval were converted to percentages so the absolute discrepancy percentages for each of the five intervals could be averaged to create an overall absolute discrepancy percentage for each participant. Larger percentages indicate a larger overall discrepancy between reproduced and presented durations.

The coefficient of accuracy score is equal to the participant's estimate of the duration divided by the actual duration. This score indicates whether participants are more likely to underestimate or overestimate the duration in their reproduction. Coefficient of accuracy scores did not need to be converted to percentages. Coefficient of accuracy scores were calculated for each of the five intervals. These five scores were averaged to create an overall coefficient of accuracy score for each participant.

Reliability estimates from the Light Bulb Game were examined. A correlation matrix of participants' absolute discrepancy percentage scores at each of the time intervals (2, 4, 6, 8, and 10 seconds) indicated that these scores were not all significantly correlated with one another. The data is presented in table 2. Together, the five different intervals produced a Cronbach's alpha of .71 indicating moderate internal reliability for the absolute discrepancy percentage scores.

Table 2.
Pearson Correlations Between the Absolute Discrepancy Percentages (ADP) of the Time Intervals

	ADP 2	ADP 4	ADP 6	ADP 8	ADP 10
ADP 2					
ADP 4	.36*				
ADP 6	.34*	.41**			
ADP 8	.35*	.37**	.18		
ADP 10	.43**	.31*	.23	.53**	

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

The coefficient of accuracy scores were analyzed in the same way. A correlation matrix indicated that participants' scores at each of the five intervals were not all significantly correlated with one another either. This data is presented in table 3. The five intervals produced a Cronbach's alpha of .69 indicating moderate internal reliability for the coefficient of accuracy scores.

Table 3.
Pearson Correlations Between the Coefficients of Accuracy (COA) of the Time Intervals

	COA 2	COA 4	COA 6	COA 8	COA 10
COA 2					
COA 4	.53**				
COA 6	.41**	.60**			
COA 8	.03	.24	.31*		
COA 10	.35*	.36**	.38**	.50*	
*Correlation is significant at the 0.05 level (2-tailed).					
**Correlation is significant at the 0.01 level (2-tailed).					

Time Sense (Time Discrimination Task). Time Sense is a computer-administered, visual test of time perception that was designed specifically for this experiment using Sony Vegas 7.0 software. Time Sense was administered to measure participants' ability to accurately discriminate between different time intervals. Time Sense was designed based on work by Levin, Goldstein & Zeiniker (1984); however, the task was altered to make it more difficult for adults. During each trial, three words were presented on the computer screen. The words were presented in different places on the screen (the top third, the middle third and the bottom third of the screen). This allowed the words to begin at the same or different times and also end at the same or different times. For example, Trial 1 lasts for a total of 12 seconds. The word "Bottom" (appearing in the bottom third of the screen) appears at the start of the first second (the beginning of the trial) and disappears at the end of the 10^{th} second (for a total of 10 seconds). The word "Middle" appears in the middle third of the screen at the start of the 6^{th} second and disappears at the end of the 11^{th} second (for a total of 6 seconds). The word "Top" appears in the top third of the screen at the beginning of the 10^{th} second and disappears at the end of the 12th second (for a total of 2 seconds). A visual representation of trial 1 is presented in figure 1.

<table>
<tr><td>Second:</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td></tr>
<tr><td rowspan="3">Screen:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Top</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="6">Middle</td><td></td></tr>
<tr><td colspan="10">Bottom</td><td></td><td></td></tr>
</table>

Figure 1. This is a visual representation of trial 1 of Time Sense.

At the end of each trial, participants were asked to use a response sheet to indicate which of the three words was on the screen for the longest amount of time. Participants were asked to bubble in the circle next to the word (“Top”, “Middle” or “Bottom”) they thought was on the screen for the longest amount of time. The correct response for Trial 1 is “Bottom.”

Time Sense consists of a total of 36 trials. Participants were given one point for each correct response; the total score was equal to the total number of correct responses. Possible scores ranged from 0 to 36. Overall, Time Sense used the same time intervals as the Light Bulb Game (intervals of 2, 4, 6, 8, and 10 seconds). Eighteen trials involve stimuli with lengths of 2, 6 and 10 seconds (as in the previously discussed example, trial 1). The other 18 trials involve stimuli with lengths of 4, 6, and 8 seconds. In addition, two versions of Time Sense were created. Version 1 contained the 36 items in a randomized order; Version 2 used the items in the reverse order of Version 1.

Three levels of difficulty were included in Time Sense. These levels of difficulty were based on the hypothesis that working memory is a limited capacity system

(Baddeley, 2003) and that increasingly difficult time discrimination items would exceed the capacity of working memory and require participants to rely more on their sense of time. So, easier items may be able to be solved via the use of working memory; however, more difficult trials will exceed the capacity of working memory and require participants to rely on their sense of time in order to correctly answer the items.

The first 12 items were considered to be "Easy." Six of these trials presented participants with three words that all started at the same time, but ended at different times. The other six trials presented participants with three words that started at different times but all ended at the same time. Participants were expected to able to solve these items simply by relying on working memory. Next, 12 "Medium" items were created. Six items presented participants with two words that started at the same time, but all the words ended at different times. The other six trials involved words that started at different times, but two of the words ended at the same time. These trials were expected to begin to exceed the capacity of working memory and require participants to utilize their sense of time. Finally, 12 "Difficult" items were created. These 12 trials presented participants with three words that both started and ended at different times. These items were designed to exceed the capacity of working memory and require participants to rely on their sense of time. These 12 trials were constructed to represent the purest measure of sense of time.

The reliability of Time Sense was investigated. The 36 items comprising Time Sense were used to generate an overall internal reliability estimate. The 36 items returned a Cronbach's alpha of .86 indicating good internal reliability.

Behavioral Inhibition System / Behavioral Activation System (BIS/BAS). The Behavioral Inhibition System / Behavioral Activation System (BAS/BIS) Scale assesses two enduring, motivational systems thought to underlie behavior and affect. The Behavioral Activation System (BAS) is believed to regulate appetitive motives, in which the goal is to move toward something desired. The Behavioral Inhibition System (BIS) is thought to regulate aversive motives, in which the goal is to move away from something unpleasant (Carver & White, 1994). The BIS portion of the scale will be utilized in this experiment. According to Gray (1978), the Behavioral Inhibition System is related to negative affect and is tied to emotions such as anxiety, fear, frustration and sadness. This is somewhat different from the concept of inhibition as it is being discussed in this paper. The BIS scale is more closely tied to the concepts of anxiety and fear rather than the ability to inhibit a prepotent response as discussed by Barkley.

The Behavioral Inhibition System is measured by 7 items. Participants are asked to respond to each of the 7 items using a 4-point scale where responses range from 1 ("very true for me") to 4 ("very false for me"). Most items are reverse scored with the result that higher BIS scores are representative of greater anxiety proneness or, according to Carver & White (1994), a tendency to inhibit behavior leading to punishment or negative outcomes. Low scores indicate a tendency to have difficulty inhibiting behavior that might lead to punishment. Possible scores on the BIS subscale range from 7 to 28. The internal reliability of the BIS scale is reported to be .74 (Carver & White, 1994).

Adult Behavior Rating Scale – Self-Report of Current Behavior. The Adult Behavior Rating Scale – Self-Report of Current Behavior (Barkley, 1997b) is 26 item self-report scale used to measure symptoms of Attention-Deficit/Hyperactivity Disorder in adults. Participants were asked to respond to each item using a 4-point scale where responses range from 0 (never or rarely) to 3 (very often). The scale returns a total score as well as separate scales measuring Attention-Deficit/Hyperactivity Disorder, Oppositional Defiant Disorder and Conduct Disorder. The total score on the ADHD scale was used for this experiment. Possible scores on the ADHD subscale range from 0 to 54, higher scores indicate a greater concordance with symptoms of ADHD. The 18 items of the ADHD scale returned a Cronbach's alpha of .78 indicating good internal reliability.

State-Trait Anxiety Inventory (STAI) – Trait. The Trait scale from the State-Trait Anxiety Inventory (Spielberger, 1983) is a 20 item scale used to measure anxiety. The trait scale was chosen to reflect the conceptualization of anxiety as a personality trait. This is consistent with Gray's definition of anxiety (Torrubia, Avila, Molto & Caseras, 2001). Each item is a description of subjective, somatic, or panic-related symptoms of anxiety. Items are scored from 1 ("Not At All) to 4 ("Very Much"). The total trait score was utilized in this experiment. Possible scores on the trait score range from 20 to 80 with higher scores indicating greater amounts of trait anxiety. The internal reliability of the STAI-T ranges from .65 to .86 (Spielberger, 1983).

Procedure

Participants participated in one testing session lasting approximately 1 to 1.5 hours. Participants began by completing informed consent. Afterwards, participants were oriented to the testing process and given an overview of the different instruments they would be completing. Next, participants were administered Digit Span and Spatial Span in individual rooms (half the participants completed Digit Span first; the other half completed Spatial Span first). Digit Span and Spatial Span were administered by first and second year clinical psychology graduate students who were blind to the overall purpose of the study. The participants then returned to a group room to complete the computer-administered tasks as well as the set of questionnaires. All of the tasks administered in the group room were silent, visual-based tasks. A quiet environment was established in this room in order to minimize auditory distractions. In addition, participants were seated 2 seats apart so as to minimize visual distractions due to nearby computer screens.

Analysis

Correlation and regression were used to test the hypothesis that inhibition (as measured by commission errors on the Go/No Go task) is related to sense of time. In this experiment, sense of time was measured through three variables (the overall absolute discrepancy percentage from the Light Bulb Game, the overall coefficient of accuracy scores from the Light Bulb Game, and the total number of correct responses on Time Sense); each variable was tested separately. First, this investigation tested the hypothesis that inhibition is correlated with the overall absolute discrepancy percentage in the Light Bulb Game. Second, this investigation tested the hypothesis that inhibition is correlated with the overall coefficient of accuracy scores in the Light Bulb Game. Third, this investigation tested the hypothesis that inhibition is correlated with the total number of correct responses in Time Sense.

Next, this investigation tested the hypothesis that working memory (as measured by scores on digit span and spatial span) is correlated with sense of time. The relative contributions of verbal and visuospatial working memory were examined. Each variable used to measure sense of time was tested separately (as described above).

Finally, this investigation tested whether clinical indices of ADHD and anxiety were correlated with sense of time. Data from the Adult Behavior Rating Scale – Self-Report of Current Behavior, State Trait Anxiety Scale – Trait and BIS/BAS scale were analyzed. Based on the results of this test, additional tests were explored.

CHAPTER 4

DATA AND ANALYSIS

Descriptive Statistics

The results were screened for normality using descriptive statistics. The descriptive data showed that the variables were normally distributed with no excessive skew or kurtosis. The descriptive statistics are reported in tables 1 and 2. Table 1 presents descriptive statistics including the minimum and maximum scores as well as means and standard deviations. Table 2 presents data regarding skewness and kurtosis.

Table 4.
Descriptive Statistics

	Minimum	Maximum	*M*	*SD*
Spatial Span	9.00	23.00	17.30	2.73
Digit Span	11.00	26.00	17.54	3.50
Time Sense Correct	23.00	35.00	31.20	2.55
Average Absolute Discrepancy Percentage	6.09	29.83	14.98	5.32
Average Coefficient of Accuracy	0.70	1.08	0.89	0.07
Commission Percentage	0.50	56.36	25.29	14.16
ADHD - Self Report of Current Behavior	1.00	35.00	12.50	8.16
STAI – Trait	27.00	71.00	41.46	9.95
BIS	14.00	28.00	21.22	3.51

Table 5.
Skewness and Kurtosis

	Skewness		Kurtosis	
	Statistic	*SE*	Statistic	*SE*
Spatial Span	-0.60	0.34	0.96	0.66
Digit Span	0.18	0.34	-0.86	0.66
Time Sense Correct	-1.17	0.34	1.98	0.66
Average Absolute Discrepancy Percentage	0.59	0.34	0.03	0.66
Average Coefficient of Accuracy	0.10	0.34	0.31	0.66
Commission Percentage	0.48	0.34	-0.52	0.66
ADHD - Self Report of Current Behavior	1.20	0.34	0.58	0.66
STAI – Trait	0.70	0.34	0.45	0.66
BIS	-0.16	0.34	-0.60	0.66

Correlations between Measures of Sense of Time

As discussed in the literature review, the Light Bulb Game and Time Sense were intended to measure different aspects of sense of time. The Light Bulb Game was intended to measure a participant's ability to accurately reproduce time intervals while Time Sense was designed to measure a participant's ability to accurately discriminate between different time intervals. The correlations between these measures were examined to see if these measures truly reflected separate concepts.

The two measures from the Light Bulb Game (the average absolute discrepancy percentage and the average coefficient of accuracy scores) were significantly correlated with each other ($r = -.73$). The average absolute discrepancy percentage was intended to measure the size of participants' errors on the Light Bulb Game (larger percentages indicate a larger discrepancy between the presented and reproduced durations). The average coefficient of accuracy score was intended to measure whether a participant was more likely to underreproduce or overreproduce durations in the Light Bulb Game (scores less than 1.0 indicate a tendency to underreproduce time intervals, scores of 1.0 indicate perfect accuracy and scores greater than 1.0 indicate a tendency to overreproduce time intervals). The descriptive data for the average coefficient of accuracy scores indicate that the majority of participants tended to underreproduce durations ($M = 0.89$, $SD = 0.07$); so, the average coefficient of accuracy scores seem to represent a transformation of the average absolute discrepancy percentages towards absolute values. Therefore, results are reported for the average absolute discrepancy percentage because this variable seemed to offer the best representation of the concept of time reproduction (the difference between the actual and reproduced durations).

Neither of the measures from the Light Bulb Game was significantly correlated with scores on Time Sense (*r* = -.13 for the average absolute discrepancy percentage and *r* = -.05 for the average coefficient of accuracy). This provides evidence that sense of time is multidimensional and the Light Bulb Game and Time Sense measure different aspects of it. Therefore, the results from the Light Bulb Game and Time Sense were examined separately.

Tests of Equivalency

Before beginning the analyses, Version 1 and Version 2 of Time Sense were examined for equivalency (Version 1 contained the 36 items in a randomized order; Version 2 used the items in the reverse order of Version 1). Twenty-six participants completed Version 1 (*M* = 31.27, *SD* = 2.55), while 24 participants completed Version 2 (*M* = 31.12, *SD* = 2.59). An independent groups t test indicated that participants did not perform significantly differently on the two versions of the test, $t(48) = .20$, $p = .84$.

Several levels of difficulty were included in Time Sense (an easy level, a medium level and a difficult level). Items from the more difficult levels were designed to exceed the capacity of working memory and require participants to rely more on their sense of time. Participants were expected to score higher on the easy level and lower on the difficult level. Table 3 presents descriptive data for the three levels of difficulty. A one-way ANOVA showed a main effect of level of difficulty, $F(2, 33) = 6.94$, $p < .01$. This indicates that Time Sense performed as expected.

Table 6.
Time Sense Descriptive Data

	M	*SD*
Easy Level	11.44	0.88
Medium Level	10.08	1.21
Difficult Level	9.68	1.48

Finally, half of the participants completed Digit Span before Spatial Span; the other half completed Spatial Span before Digit Span. Therefore, two independent groups *t* tests were used to test for order effects (one *t* test was used to examine Spatial Span scores, the other was used to examine Digit Span scores). For one participant, it was unclear whether Digit Span or Spatial Span was administered first, so this participant was omitted for the following *t* tests. The two groups did not perform differently on Spatial Span $t(47) = -.80$, $p = .43$. They also did not perform differently on Digit Span $t(47) = .56$, $p = .58$.

Correlations between Inhibition and Sense of Time

Pearson correlations were used to test the hypothesis that inhibition is related to sense of time. Inhibition was measured by using the percentage of commission errors on the Go/No Go task (with higher percentages indicating a greater amount of commissions). The two variables measuring sense of time (average absolute discrepancy percentage from the Light Bulb Game and total number of correct responses on Time Sense) were tested separately. Average absolute discrepancy percentage on the Light Bulb Game was not correlated with inhibition ($r = -.19$). The total number of correct responses on Time Sense was also not correlated with inhibition ($r = -.09$). This indicates that there was not a significant correlation between inhibition and participants' ability to reproduce or discriminate between time intervals.

Correlations between Working Memory and Sense of Time

Next, multiple regression was used to test the hypothesis that working memory is correlated with sense of time. Scores on Digit Span and Spatial Span were loaded as independent variables. Average absolute discrepancy percentage on the Light Bulb Game was not correlated with working memory (*R* = .18). The standardized beta weights for Spatial Span and Digit Span were .16 and -.12, respectively. However, the total number of correct responses on Time Sense was significantly correlated with working memory, ($R = .47$, $p < .01$). Together, Spatial Span and Digit Span accounted for 21.8% of the variance. The standardized beta weights for the Spatial Span and Digit Span were .39 and .19, respectively.

Using a Pearson correlation, Digit Span and Spatial Span were not significantly correlated with one another ($r = .18$); therefore, Spatial Span and Digit Span were entered as separate predictors to see if either predicted above and beyond the other. When Spatial Span and Digit Span were entered sequentially into block 1 and block 2, Digit Span did not predict significantly above Spatial Span ($\Delta R^2 = .04$, $p = .16$), but Spatial Span did predict significantly over Digit Span ($\Delta R^2 = .15$, $p < .01$).

Forward and Backward scores were also tested to see if either would predict above and beyond the other. Total score on Time Sense was again entered as a dependent variable. When tested in a stepwise manner, neither Digit Forward nor Digit Backward predicted significantly above one another. However, Spatial Backward did predict significantly above Spatial Forward ($\Delta R^2 = .08$, $p = .04$). This indicates that the manipulation aspects of visuospatial working memory seem to be more correlated with Time Sense than the maintenance aspects of visuospatial working memory. Finally, difference scores were also calculated for both Digit Span and Spatial Span by subtracting participants' Backward score from their Forward score. Neither difference score was significantly correlated with the total score on Time Sense.

Due to the fact that inhibition was not significantly correlated with any of the variables measuring sense of time, the hypothesis that inhibition contributes to sense of time above and beyond working memory was not able to be tested.

Correlations between Self-Report Measures and Sense of Time

Next, multiple regression was used to test the hypothesis that self-report measures of ADHD, trait anxiety and the behavioral inhibition system would be correlated with sense of time. The total ADHD score from the Adult Behavior Rating Scale, the Trait score from the State Trait Anxiety Inventory, and the BIS scale from the BIS/BAS were entered together as independent variables. These measures were not correlated with the average absolute discrepancy percentage on the Light Bulb Game (R = .25). However, the measures were significantly correlated with the total score on Time Sense (R = .42, p = .03). Together, the self-report measures accounted for 17.3% of the variance. However, although the ADHD score and the STAI-T score were both significant predictors, the BIS scale was not a significant predictor (the standardized beta weight for the BIS scale was .00). Therefore, the BIS was discarded at this point in the analysis. The standardized beta weights for the ADHD score and STAI-T Trait score were -.39 and .38. To see if either variable predicted above the other, ADHD and STAI-T were entered sequentially into block 1 and block 2 (with the total score on Time Sense again entered as the dependent variable). ADHD predicted significantly above STAI-T (ΔR^2 = .12, p = .01) and STAI-T also predicted significantly above ADHD (ΔR^2 = .12, p = .01). This indicates that both variables made significant contributions to Time Sense above and beyond the other.

These results indicate that, as self-report symptoms of ADHD increased, total score on Time Sense decreased. However, although this experiment expected to find a negative correlation between symptoms of ADHD and time discrimination ability, the positive correlation between trait anxiety and time discrimination was somewhat surprising. These results indicate that, as self-reported symptoms of trait anxiety increased, total score on Time Sense also increased. A correlation matrix was used to examine which items may have contributed to this correlation. The mean scores of three items showed a significant correlation with total score on Time Sense. The first item, which is reverse-scored, was "I am calm, cool, and collected" ($r = .33$, $p = .02$). "I feel secure" ($r = .38$, $p < .01$) is also reverse-scored. Finally, "I take disappointments so keenly that I can't put them out of my mind" ($r = .30$, $p = .04$) was also significantly correlated with total score on Time Sense.

Correlations between Self-Report Measures, Working Memory and Sense of Time

Next, multiple regression was used to determine whether the self-report measures contributed unique variance to total score on Time Sense above and beyond working memory. Total score correct on Time Sense was again used as the dependent variable. Digit Span and Spatial Span were entered together in block 1 while ADHD and STAI-T scores were entered together in block 2. Together, all four variables accounted for 36.7% of the variance ($R = .61$, $p <.01$). As predicted, the self-report measures contributed significantly beyond working memory ($\Delta R^2 = .15$, $p <.01$).

As discussed earlier, Time Sense contained three levels of difficulty. Multiple regression was used to test the hypothesis that, as the level of difficulty increased, the items would exceed the capacity of working memory and require participants to rely on their sense of time. Each of the three levels of difficulty was tested separately as a dependent variable. Digit Span and Spatial Span were entered as independent variables in block 1 while ADHD and STAI-T scores were entered as independent variables in block 2. First, the 12 easy trials of Time Sense were used as the dependent variable. There was no significant overall relationship at this level (R = .37). Next, the 12 medium trials of Time Sense were used as the dependent variable. This did result in a significant overall correlation (R = .45, p = .03). Working memory scores (Digit Span and Spatial Span) accounted for 18.3% of the variance (R = .43). The self-report measures did not predict above and beyond working memory (ΔR^2 = .02). Next, the 12 difficult trials of Time Sense were entered as the dependent variable. This resulted in a significant overall correlation (R = .55, p <.01). At block 1, Digit Span and Spatial Span accounted for 10.1% of the variance (R = .32), but the p-value for working memory dropped just below significance (p = .08) without the self-report measures. At block 2, as expected, the self-report measures predicted additional variance above and beyond working memory (ΔR^2 = .21, p <.01). The standardized beta weights for ADHD and STAI-T were -.46 and .35, respectively. Both were significant predictors. These results support the hypothesis that it is the purer aspects of sense of time that are related to ADHD and anxiety.

CHAPTER 5

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

This aim of this study was to test the relationships between inhibition, working memory and sense of time. Sense of time was measured using two tasks. The Light Bulb Game was used to measure time interval reproduction and Time Sense was used to measure time interval discrimination.

This study began by investigating the hypothesis that inhibition is related to sense of time. Inhibition was not related to either time reproduction or time discrimination. This result is striking because it conflicts with the relationships specified in Barkley's (1997a) theory of ADHD. Therefore, it is possible that inhibition is not related to sense of time in a non-clinical population. However, it is also possible that this result may be attributable to limitations in the Go/No Go task used in the current study. Kerns, McInerney and Wilde (2001) explored the relationship between inhibition and time reproduction using a Go/No Go task and the Light Bulb Game with a group of children ages 6-13. The Go/No Go task used in this experiment flashed stimuli on the screen at a rate of one per second. The Go/No Go task used in the current study (with college students ages 18-29) was designed to flash stimuli on the screen at a rate of one every two seconds. Furthermore, if the space bar was not pressed, the stimuli did not disappear from the screen until 2000ms. Allowing stimuli to persist on the screen for a longer period of time might have made the task easier by allowing participants to slow their rate of responding. This could have reduced commission errors and made it more difficult to establish relationships between inhibition and some of the other variables in the study (including time reproduction and time discrimination). Future studies might benefit from flashing stimuli on the screen at a faster rate to make the task more challenging for adults.

Next, this experiment tested the hypothesis that time reproduction is related to working memory, ADHD and anxiety. Previous research has shown the Light Bulb Game to be a useful paradigm for measuring time reproduction; however, data from the Light Bulb Game was not related to working memory, ADHD or anxiety. Therefore, it is possible that time reproduction is not linked to any of these variables in a non-clinical population.

However, it is also possible that some limitations in the time reproduction task may have contributed to this result. It should be noted that the examiner chose to administer only the visual portion of the task (rather than also administering the auditory portion of the task), but this choice was consistent with previous findings regarding the Light Bulb Game (Kerns, McInerney & Wilde, 2001; West et al., 2000). However, this experiment did choose to utilize different time intervals than previous studies. Barkley, Murphy and Bush (2001) found differences between a control group and a group of young adults diagnosed with ADHD (participants ranged from age 17 to age 28). Barkley, Bush and Murphy (2001) used intervals of 2, 4, 12, 15, 45, and 60 seconds in this experiment; however, they did not utilize the Light Bulb Game (please refer to the literature review for an overview of the time reproduction procedure used in this study). Barkley, Murphy and Bush found group differences at the 12, 45 and 60 second intervals. The current study chose to utilize shorter time intervals (2, 4, 6, 8 and 10 seconds) with the hypothesis that these time intervals would be more challenging to the non-clinical population being tested in this experiment. However, time reproduction was not related to working memory, ADHD or anxiety using these intervals, so future studies may wish to consider using longer time intervals with an adult population.

This experiment tested the hypothesis that time discrimination is related to working memory, ADHD and anxiety. Time discrimination was significantly related to working memory. Further analyses revealed that visuospatial working memory predicted additional variance above and beyond verbal working memory. In addition, when Spatial Span was broken down into its respective components (Spatial Span Forward and Spatial Span Backward), Spatial Span Backward predicted additional variance above and beyond Spatial Span Forward. This indicates that participants were relying more on their ability to manipulate information rather than simply their ability to maintain information in working memory. Sense of time and visual processing are both localized within the right hemisphere of the brain, so this may account for some of the variance in the relationship between time discrimination and visuospatial working memory. However, Time Sense is also a visual task in which position is important, so this may also have contributed to the significantly higher correlation between time discrimination and Spatial Span.

Next, this study examined the hypothesis that time discrimination is related to self-report measures of ADHD, trait anxiety and the behavioral inhibition system. Self-report measures of ADHD, trait anxiety and the behavioral inhibition system were significantly related to time discrimination. Further analysis showed that ADHD and anxiety were the significant predictors. When tested in stepwise fashion, symptoms of ADHD and trait anxiety both predicted significantly above and beyond the other. The correlations indicated that higher ADHD scores were correlated with lower time discrimination scores. However, as self-report symptoms of trait anxiety increased, time discrimination ability also increased. This effect was surprising, so additional research was explored that might provide insight into the positive correlation between time discrimination and anxiety.

The Yerkes-Dodson law states that the relationship between arousal and working memory is best described as an inverted-U (Christianson, 1992). A closer inspection of participants STAI-T scores in this experiment shows that very few participants' scores on the trait scale the entered the clinical range (M = 41.46, SD = 9.94). So, the results of this study may indicate that, in a sub-clinical population, a healthy amount of trait anxiety is associated with arousal which facilitates a more well-developed ability to discriminate between different time intervals. It is possible that a heightened sense of anxiety may aid in the discrimination between time intervals; however, it is also possible that persons who have a tendency to attend more closely to the passage of time may also be more anxious. Future studies may wish to explore the inverted-U relationship between anxiety and sense of time in greater detail.

Furthermore, there is evidence that the different components of working memory respond differently to the presence of anxiety. Although anxiety has a tendency to impair the central executive and phonological loop portions of working memory, it does not seem to impact the visuospatial sketchpad (Eysenck, Payne & Derakshan, 2005). Perhaps this finding extends to sense of time as well. This may explain the higher correlation between visuospatial working memory and time discrimination. So, it is possible that the increased presence of anxiety has minimal effects on the ability to discriminate between time intervals.

Finally, three items on the STAI-T were significantly correlated with time discrimination ability. These items were analyzed in order to provide more insight into the positive correlation between anxiety and time discrimination. The items, “I am calm, cool and collected” (reverse scored), “I feel secure” (reverse scored), and “I take disappointments so keenly that I can’t put them out of my mind,” suggest that feeling somewhat keyed-up, on-edge, insecure, or hyperfocused may be associated with a more well-developed sense of time.

Finally, working memory was added in order to examine the relationships between time discrimination, working memory and self-report measures of ADHD and trait anxiety. Time discrimination was significantly related to working memory, ADHD and anxiety. When tested in a stepwise manner, self-report measures of ADHD and trait anxiety predicted additional variance above and beyond working memory with respect to time discrimination. This indicates that ADHD and anxiety make important contributions to sense of time above and beyond working memory.

This experiment explored this relationship in more detail by testing the hypothesis that increasingly difficult time discrimination items would exceed the capacity of working memory and require participants to rely more on their sense of time. In order to test this hypothesis, the three levels of Time Sense were used as separate dependent variables. When tested in isolation, the easy level trials were not significantly related to working memory and the self-report measures. This lack of a correlation with the easy trials may have been due to restricted range (M = 11.44, SD = 0.84 for the easy trials). There was a significant correlation at the medium level. The medium level trials were significantly correlated with working memory, but ADHD and trait anxiety did not predict additional variance above working memory. This indicates that participants were able to solve the medium level items using working memory. The items were not difficult enough to exceed the capacity of working memory and push participants to rely on their sense of time. At the difficult level, there was a significant correlation between time discrimination, working memory, ADHD and trait anxiety. As predicted, the relationship between working memory and time discrimination dropped just below significance at block 1. Also as hypothesized, ADHD and trait anxiety predicted significantly above working memory. These results indicate that participants were not able to solve the more difficult items simply by relying on working memory. These items forced participants to rely more on their sense of time. These results support a relationship between a "purer" sense of time and symptoms of ADHD and anxiety.

Future research should continue to directly examine the relationships between sense of time, inhibition and working memory. In particular, the correlation between inhibition and sense of time deserves further consideration as this study was not able to establish a relationship.

In addition, future research might also explore the relationships between working memory and sense of time using another modality. For example, the results of this study showed a correlation between time discrimination and visuospatial working memory. However, Time Sense is a visual task, so future research might utilize an auditory task to measure participants' time discrimination abilities. Such a task might utilize different pitches (a high pitch, a medium pitch and a low pitch note) in the same way visual stimuli were used in the present study. It would be interesting to note the relative contributions of verbal and visuospatial working memory to such as task. Furthermore, a study might combine auditory and visual stimuli by panning different audiovisual stimuli to different places within a stereo imagine (i.e. one stimulus could be placed in the left speaker/left side of the screen, a second stimulus could be placed in the right speaker/right side of the screen and a third stimulus could be placed in the center).

Finally, future studies should explore the relationship between sense of time and anxiety in greater detail. This study established a relationship between self-report scores of trait anxiety and participants' ability to discriminate between different time intervals. It would be interesting to test for an "inverted-U" relationship between anxiety and sense of time. A future study could obtain physiological as well as self-report measures of anxiety. In addition, a study might compare participants using a repeated measures design. An experimenter could administer sense of time tests under "normal" conditions, then measure participants' sense of time again during "anxious" conditions.

REFERENCES

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., text rev.). Washington, DC: Author.

Applegate, B., Lahey, B.B., Hart, E.L., Waldman, I., Biederman, J., Hynd, G.W., Barkley, R.A., Ollendick, T., Frick, P.J., Greenhill, L., McBurnett, K., Newcorn, J., Kerdyk, I., Garfinkeln, B., & Shaffer, D. (1997). Validity of the age of onset criterion for ADHD: A report from the *DSM-IV* field trials. *Journal of the American Academy of Child and Adolescent Psychiatry*, *36,* 1211-1221.

Avila, C. & Parcet, M.A. (2001). Personality and inhibitory deficits in the stop-signal task: The mediating role of Gray's anxiety and impulsivity. *Personality and Individual Differences, 31*, 975-986.

Baddeley, A. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829-839.

Baddeley, A.D., & Logie, R.H. (1999). *Working memory: The multiple component model.* In Shah, P. & Miyake, A. (Eds.), *Models of Working Memory* (pp. 1-27). Cambridge, UK: Cambridge University Press.

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

Barkley, R.A. (1997b). *Defiant children: A clinician's manual for assessment and parent training (2nd ed.)* New York: Guilford Publications.

Barkley, R.A. (1998). *Attention Deficit Hyperactivity Disorder.* New York: The Gilford Press.

Barkley, R.A. (1998). *Time perception application, (version 1.0) (Computer software).* University of Massachusetts Medical Center: Chesapeake Technology.

Barkley, R.A. (2000). Genetics of childhood disorders: XVII. ADHD, Part 1: The executive functions and ADHD. *Journal of the American Academy of Child and Adolescent Psychiatry, 39,* 1064-1068.

Barkley, R.A., Edwards, G., Laneri, M., Fletcher, K., & Metevia, L. (2001). Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology, 29*, 541-556.

Barkley, R.A., Fischer, M., Smallish, L. & Fletcher, K. (2002). The persistence of attention-deficit/hyperactivity disorder into young adulthood as a function of reporting source and definition of disorder. *Journal of Abnormal Psychology, 111(2),* 279-89.

Barkley, R.A. & Gordon, M. (2002) Research on comorbidity, adaptive functioning, and cognitive impairments in adults with ADHD: Implications for a clinical practice. In Goldstein, S. & Ellison, A.T. (Eds). *Clinician's guide to adult ADHD: Assessment and Intervention.* San Diego: Academic Press.

Barkley, R.A., Koplowitz, S., Anderson, T., & McMurray, M.B. (1997). Sense of time in children with ADHD: Effects of duration, distraction, and stimulant medication. *Journal of the International Neuropsychological Society, 3*, 359-369.

Barkley, R.A. Murphy, K.R., & Bush, T. (2001). Time perception and reproduction in young adults with attention deficit hyperactivity disorder. *Neuropsychology, 15,* 315-360.

Bauermeister, J.J., Barkley, R.A., Martinez, J.V., Cumba, E., Ramirez, R.R., Reina, G., Matos, M., & Salas, C.C. (2005). Time estimation and performance on reproduction tasks in subtypes of children with attention deficit hyperactivity disorder. *Journal of Clinical Child and Adolescent Psychology, 34,* 151-162.

Biederman, J., Faraone, S.V. (2005). Attention-deficit hyperactivity disorder. *Lancet, 366,* 237-248.

Biederman, J., Mick, E., & Faraone, S.V. (2000). Age-dependent decline of symptoms of attention deficit hyperactivity disorder: Impact of remission definition and symptom type. *American Journal of Psychiatry, 157,* 816-818.

Block, R.A. (1990). Models of psychological time. In R.A. Block (Ed.), *Cognitive models of psychological time.* Lawrence Erlbaum: Hillsdale, New Jersey.

Block, R.A. & Zakay, D. (2006). Prospective remembering involves time estimation and memory processes. In Glicksohn, J. & Myslobodsky, M.S. (Eds.), *Timing the future: The case for a time-based prospective memory.* World Scientific Publishing Company: Hackensack, NJ.

Bridgett, D.J. & Walker, M.E. (2006). Intellectual functioning in adults with ADHD: A meta-analytic examination of full scale differences between adults with and without ADHD. *Psychological Assessment, 18,* 1-14.

Carver, C.S. & White, T.L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology, 67,* 319-333.

Christianson, S.-A. (1992). Emotional stress and eyewitness memory: A critical review. *Psychological Bulletin, 112,* 284-309.

Church, R.M. (1984). Properties of the Internal Clock. In Gibbon, J. & Allan, L (Eds.), *Timing and Time Perception* (pp. 566-582). New York: The New York Academy of Sciences.

Clarke, S., Heussler, H., Kohn, M.R. (2005). Attention deficit disorder: Not just for children. *International Medicine Journal, 35*, 721-725.

Dige, N.S. & Wik, G. (2005). Adult attention deficit hyperactivity disorder identified by neurological testing. *International Journal of Neuroscience, 115,* 169-183.

Ericsson, K.A. & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*, 211-245.

Eysenck, M.W., Payne, S. & Derakshan, N. (2005). Trait anxiety, visuospatial processing, and working memory. *Cognition and Emotion, 19*, 1214-1228.

Fuster, J.M. (1995). Memory and planning: Two temporal perspectives of frontal lobe function. In H.H. Jasper, S. Riggio, & P.S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 9-18). New York: Raven Press.

Gittelman, R, Mannuzza, S, Shenker, R, Bonagura, N. (1985). Hyperactive boys almost grown up, I: Psychiatric status. *Archives of General Psychiatry, 42*, 937–947.

Gray, J.A. (1978). The neuropsychology of anxiety. *British Journal of Psychology, 69*, 417-434.

Gray, J.A. (1987). Perspectives on anxiety and impulsivity: A commentary. *Journal of Research in Personality, 21,* 493-509.

Harrington, D.L., Haaland, K.Y., & Knight, R.T. (1998). Cortical networks underlying mechanisms of time perception. *The Journal of Neuroscience, 18,* 1085-1095.

International Consensus Statement on ADHD. (2002). *Clinical Child and Family Psychology Review, 5*, 89-111.

Kaufman, A.S. & Lichtenberger, E.O. (1999). *Essentials of WAIS-III Assessment.* New York: John Wiley & Sons, Inc.

Kerns, K.A., McInerney, R.J., & Wilde, N.J. (2001). Time reproduction, working memory and behavioral inhibition in children with ADHD. *Child Neuropsychology, 7,* 21-31.

Kerns, K.A. & Price, K.J. (2001). An investigation of prospective memory in children with ADHD. *Child Neuropsychology, 7*, 162-171.

Kessler, R.C., Adler, L., Barkley, R., Biederman, J., Connors, C.K., Demler, O., Faraone, S.V., Greenhill, L.L., Howes, M.J., Secnik, K., Spencer, T., Ustun, T.B., Walters, E.E., Zaslavsky, A.M. (2006). The prevalence and correlates of adult ADHD in the United States: Results from the national comorbidity survey replication. *The American Journal of Psychiatry, 163,* 716-723.

Kintsch, W., Healy, A.F., Hegarty, M., Pennington, B.F., & Salthouse, T.A. (1999). Eight questions and some general issues. In Shah, P. & Miyake, A. (Eds.), *Models of Working Memory* (pp. 412-441). Cambridge, UK: Cambridge University Press.

Levin, I., Goldstein, R., Zeiniker, T. (1984). The role of memory and integration in early time concepts. *Journal of Experimental Child Psychology, 37*, 262-270.

Mannuzza S., Klein, R.G., Bonagura, N., Malloy, T.L., & Addali, K.A. (1991). Hyperactive boys almost grown up, V: Replication of psychiatric status. *Archives of General Psychiatry, 48,* 77–83.

Matthys, W., van Goozen, S.H.M., de Vries, H., Cohen-Kettenis, P.T. & van Engeland, H. (1998). The dominance of behavioural activation over behavioural inhibition in conduct disordered boys with or without attention deficit hyperactivity disorder. *Journal of Child Psychology and Psychiatry, 39*, 643-651.

McInerney, R.J. & Kerns, K.A. (2003). Time reproduction in children with ADHD: Motivation matters. *Child Neuropsychology, 9*, 91-108.

Meaux, J.B. & Chelonis, J.J. (2003). Time perception differences in children with and without ADHD. *Journal of Pediatric Health Care, 17,* 64-71.

Rowland, A.S., Lesesnse, C.A. & Abramowitz, A.J. (2002). The epidemiology of attention-deficit/hyperactivity disorder (ADHD): The public view. *Mental Retardation and Developmental Disabilities Research Reviews, 8(3)*, 162-170.

Sergeant, J.A., Geurts, H., Huijbregts, S., Scjeres, A., Oosterlaan, J. (2003). The top and bottom of ADHD: a neuropsychological perspective. *Neuroscience and Biobehavioral Reviews, 27,* 583-592.

Shackman, A.J., Sarinopoulos, I., Maxwell, J.S., Pizzagalli, D.A., Lavric, A., & Davidson, R.J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion, 6,* 40-61.

Shah, P. & Miyake, A. An Introduction. In Shah, P. & Miyake, A. (Eds.), *Models of Working Memory* (pp. 1-27). Cambridge, UK: Cambridge University Press.

Smith, A.S., Taylor, E., Rogers, J.W., Newman, S., & Rubia, K. (2002). Evidence for a pure time perception deficit in children with ADHD. *Journal of Child Psychology and Psychiatry, 43,* 529-542.

Spielberger, C. D. (1983). *Manual for the State-Trait Anxiety Inventory (STAI)*. Palo Alto, CA: Consulting Psychologists Press.

Tannock, R. (2002). Cognitive correlates of ADHD. In P.S. Jensen & J. Cooper (Eds.), *Attention Deficit Hyperactivity Disorder* (pp. 8-1 – 8-27). Kingston, NJ: Civic Research Institute.

Toplak, M.E., Rucklidge, J.J., Hetherington, R., John, S.C.F., & Tannock, R. (2003). Time perception deficits in attention-deficit/hyperactivity disorder and comorbid reading difficulties in child and adolescent samples. *Journal of Child Psychology and Psychiatry, 44,* 888-903.

Torrubia, R., Avila, C., Molto, J, & Caseras, X. (2001). The sensitivity to punishment and sensitivity to reward questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. *Personality and Individual Differences, 31*, 837-862.

Voeller, K.K.S. (2004). Attention-deficit hyperactivity disorder (ADHD). *Journal of Child Neurology, 19,* 798-814.

Wechsler, D. (1997). *Wechsler Memory Scale (3rd Ed.)*. San Antonio, TX: Harcourt Assessment.

West, J., Douglas, G., Houghton, S., Lawrence, V., Whiting, K., & Glasgow, K. (2000). Time perception in boys with attention-deficit/hyperactivity disorder according to time duration, distraction and mode of presentation. *Child Neuropsychology, 6,* 241-250.

Wilens, T.E., Biederman, and Spencer, T.J. (2002). Attention deficit/hyperactivity disorder across the lifespan. *Annual Review of Medicine, 53,* 113-131.

Zakay, D. (1992). The role of attention in children's time perception. *Journal of Experimental Psychology, 54,* 355-371.

Zakay, D. & Block, R.A. (1997). Temporal Cognition. *Current Directions in Psychological Science, 6*, 12-16.

APPENDICIES

Appendix A: Barkley's Theory of ADHD

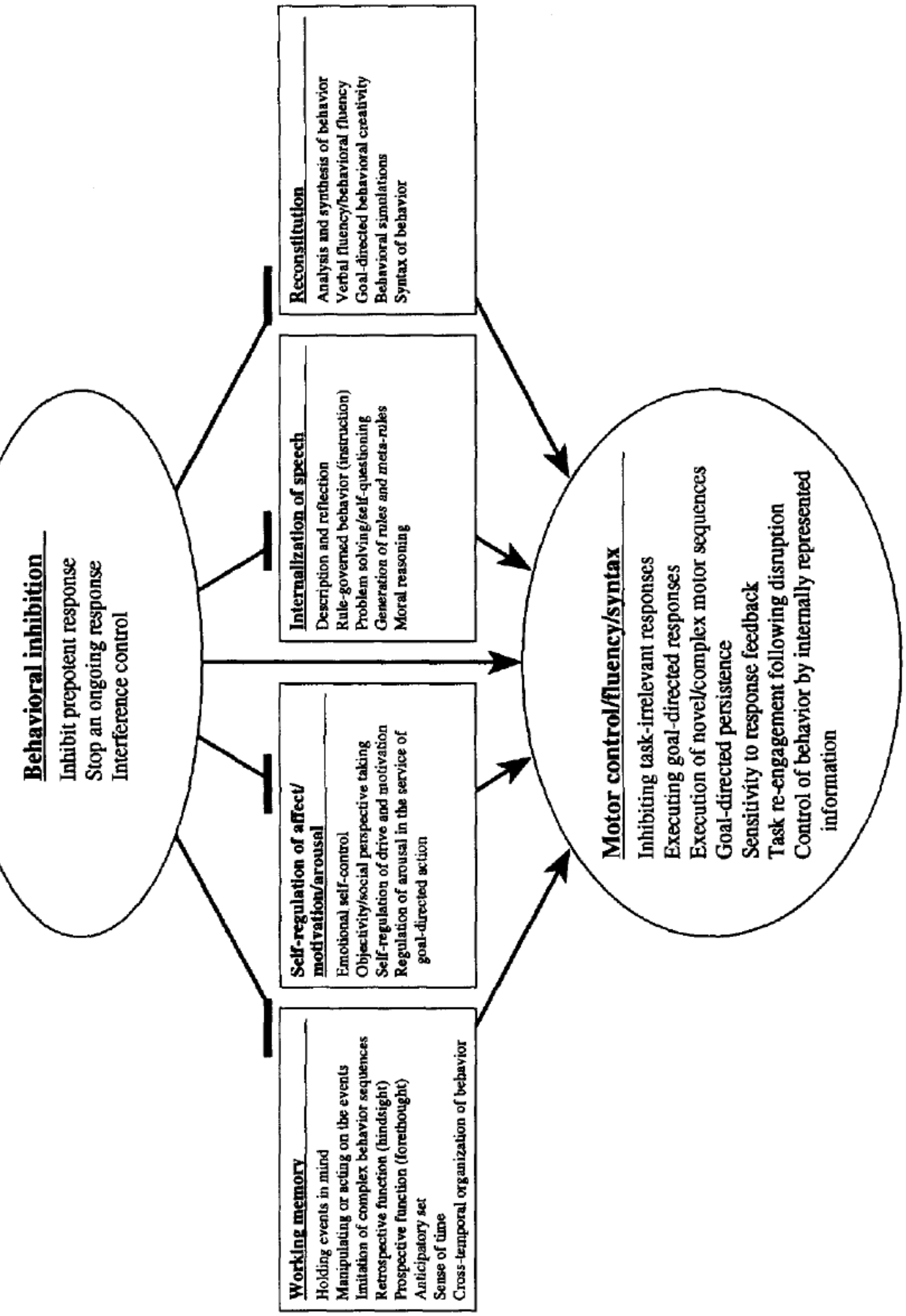

Figure 1. A schematic configuration of a conceptual model that links behavioral inhibition with the performance of the four executive functions that bring motor control, fluency, and syntax under the control of internally represented information.

Appendix B: The Attentional-Gate Model