EXPLORING THE DIAGNOSTIC UTILITY OF THE FLICKER TASK

AND THE CONTINUOUS PERFORMANCE TEST IN ADULTS WITH ADHD

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THESIS ABSTRACT

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Continuous performance tests (CPTs) are widely used to help diagnose Attention-Deficit/Hyperactivity Disorder (ADHD). However, the diagnostic utility of CPTs is generally poor. This study examined the ability of the flicker task (Rensink, O'Regan, & Clark, 1997) to serve as a more diagnostically accurate measure of ADHD than the Conners' CPT (CCPT). Flicker task and CCPT performance was compared between an ADHD (n = 28) and control (n = 30) group. The results replicate findings from Rensink et al. (1997), providing support for using the flicker task to demonstrate the robust nature of change blindness. However, the flicker task did not demonstrate better diagnostic utility than the CCPT; both tasks showed similarly weak diagnostic utility. Significant correlations with dependent measures of the two tasks were frequently common to ADHD rating scale indices of both inattention and hyperactivity/impulsivity, indicating a

lack of symptom domain specificity of CPT measures. Recommendations are provided regarding the future study of CPTs as a diagnostic measure of ADHD and the potential utility of the flicker task.

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INTRODUCTION

Change Blindness and the Flicker Task

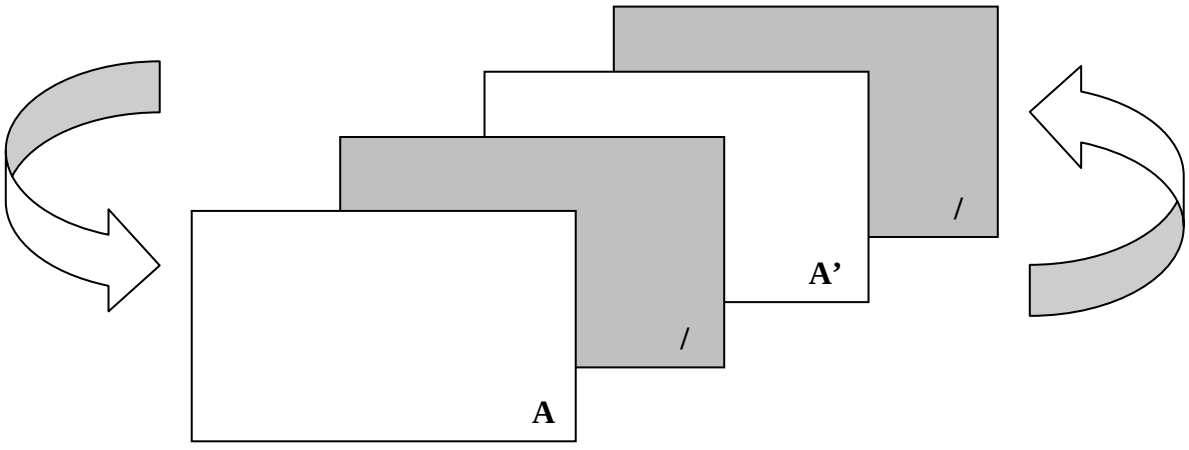
Recent research on visual memory has demonstrated that people are surprisingly poor at detecting large changes to objects, photographs, and films from one moment to the next (e.g., Simons & Levin, 1997). For example, individuals watching a movie may fail to detect the movie editing error of breaking continuity, such as when an actor's posture inadvertently changes between consecutive camera positions (e.g., when a camera angle shows an actor's hand clenched in a fist, but the next camera angle shows the hand relaxed). Under normal viewing conditions, changes to a scene generate a motion signal—an automatic, internal cue signifying a visual change—that is readily detected. However, when another event coincides with a change to a scene, this additional event disrupts the motion signal such that observers are often blind to unexpectedly large changes (Simons, 2000), a phenomenon termed *change blindness.*

Since the 1950s, researchers have noted the existence of change blindness (Simons, 2000). However, recent demonstrations have illustrated the occurrence of change blindness under naturalistic conditions, which has fueled current interest in the change blindness phenomenon. For example, research has revealed change blindness occurring during many different experimental paradigms: saccades—the small jerky movement of the eye as it jumps from one fixation point to another (Grimes, 1996); flashed blank screens—the insertion of a blank field between an original and changed

image (Rensink, O'Regan, & Clark, 1997); movie cuts—the shift in successive camera positions (Levin & Simons, 1997); real-world occlusion events—when a person's view is blocked during an in vivo interaction (Simons & Levin, 1998), and eye blinks (O'Regan, Deubel, Clark, & Rensink, 2000).

To examine change blindness, Rensink et al. (1997) developed the flicker task. In this paradigm, an original image A repeatedly alternates with a modified image A', with a blank field placed between successive images (see Figure 1). Differences between original and modified images can be of any size and type. An example of an image modification is the alternating presence and absence (addition and deletion) of an object within a scene. The observer freely views the flickering display and presses a key when the change is perceived, allowing number of cycles needed to detect the change (proportional to reaction time) to serve as a dependent measure. To prevent guessing, the observer must then correctly report the location of the scene that was changing, thus allowing accuracy to serve as an additional dependent measure. A key result of Rensink

Figure 1. The flicker task. An original image A repeatedly alternates with a modified image A', with a blank field / placed between successive images.



et al.'s (1997) work provides support for the role of attention in the flicker task and, more generally, in the change blindness phenomenon. Observers more rapidly detect changes to central interest (CI) objects than changes to marginal interest (MI) objects. CI objects capture the theme of the scene (e.g., the meal enjoyed by a couple dining out), whereas MI objects do not contain the focus of the scene (e.g., the horizon level behind the dining couple). The argument follows that the salience or thematic centrality of CI objects makes them more "interesting" than MI objects. A number of researchers have posited the attentional mechanism that more "interesting" items gain increased or prioritized attention, which leads to more rapid change detection (O'Regan et al., 2000; Rensink et al., 1997; Simons, 2000). In effect, the attention paid to "interesting" items reduces change blindness.

O'Regan et al. (2000) modified the flicker task to substantiate further that the salience of CI objects explains the decreased latency in identifying CI compared to MI changes. Using a computerized visual tracking system to monitor an observer's eye blink, these researchers alternated original and modified images only when the observer blinked. Observers searching for changes followed a stereotyped, repetitive path of visual scanning in which they never directly fixated large areas of the image. Thus, CI objects received significantly more direct fixations than did MI objects, supporting the notion that CI changes—due to their relative importance in a given scene—gather more visual attention than do MI changes and thus lead to earlier detection.

Additionally, Rensink et al. (1997) provided arguments that rule out other factors as contributing to change blindness in the flicker task. Four hundred ms are needed to process and consolidate an image in memory (Rensink et al., 1997). However, Rensink et

al. (1997) displayed images for only 240 ms in one phase of their study. This reduced image display time may have interfered with the ability to consolidate and compare successive images, such that incomplete memory consolidation may explain the occurrence of change blindness under flicker conditions. Therefore, Rensink et al. (1997) increased image display time to 560 ms. If incomplete memory consolidation was responsible for change blindness, longer displays of the image would allow for adequate memory consolidation and lead to quicker change detection. A significant level of change blindness occurred for both 240 ms and 560 ms conditions, thereby ruling out memory consolidation as a contributing factor to change blindness in the flicker task.

Another hypothesis for the occurrence of change blindness during the flicker task was poor visibility, under the assumption that the flicker of alternating images made it difficult to detect change. Consequently, Rensink et al. (1997) provided valid verbal cues regarding CI and MI changes. Valid verbal cues significantly reduced the latency to identify CI and MI objects to the point that there was no difference in the time needed to identify CI and MI changes. This study further supports the role of attention in the flicker task, as cueing the change detection may be considered a form of attentional priming (Rensink, 2002).

Researchers have concluded from results of change blindness studies that attention is necessary for change detection—details of an object may be retained only if attention is given to the changing feature (e.g., Mitroff & Simons, 2002; Simons, 2000). If observers could encode an entire scene with a single attentional fixation—that is, use a parallel search—they could detect changes anywhere in an image with equal ability. However, the change blindness phenomenon demonstrates clearly that observers do not

use parallel search. Instead, observers must serially scan a scene, placing *focused attention* on salient items first and encoding the scene piecemeal (Rensink et al., 1997). The primary definition of attention in relation to change blindness and the flicker task is that of focused attention (Rensink et al., 1997; Simons, 2000). Focused attention is the process by which an individual attempts to track one stimulus (or one type of stimulus) and ignore another, a process that typically involves both search and vigilance (Sternberg, 1999). The flicker task is an intentional change detection task in that observers know that changes will occur and actively search the display to find them. This task demonstrates that observers are change blind even when their primary task is to attend to and search for changes (Rensink et al., 1997; Simons, 2000). In short, change blindness is conceptualized as a phenomenon of attentional processing, and the flicker task is a measure used to examine it.

Attention-Deficit/Hyperactivity Disorder (ADHD)

The *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR; American Psychiatric Association [APA], 2000) characterizes ADHD along two symptom domains, inattention-disorganization and hyperactivity-impulsivity, which yields three clinical subtypes: Predominantly Inattentive (ADHD-I), Predominantly Hyperactive-Impulsive (ADHD-H), and Combined (ADHD-C). In order to meet diagnostic criteria, symptoms must have an early onset (presenting before age 7) and must be longstanding (at least six months in duration), pervasive (occurring across multiple settings), and impairing (APA, 2000). Inattentive symptoms include daydreaming, “spacing out” or being “lost in a fog,” staring frequently, and being easily confused, lethargic, and passive. Hyperactive-impulsive symptoms include being “always

on the go" (e.g., always out of seat), acting as if driven by a motor (e.g., constantly moving arms and legs while at task), and acting impulsively (e.g., blurting out answers before questions are completed). The Combined subtype includes symptoms of both the Inattentive and Hyperactive-Impulsive subtypes.

In terms of a clinical phenomenon, ADHD is one of the most commonly diagnosed childhood disorders, with a prevalence of 3-5% and male overrepresentation of approximately 3:1 (Barkley, 1997). ADHD is a lifespan disorder that emerges in early childhood and frequently persists through adolescence into adulthood. Of the clinically diagnosed childhood cases, 50-80% persist into adolescence, and 30-50% of these cases persist into adulthood (Barkley, 1997). Individuals with ADHD display difficulties with attention relative to normal peers (Barkley, 1998). Individuals with ADHD have great difficulty sustaining attention and persistence of effort to tasks. For example, children and adults with ADHD may exhibit inattention via heightened distractibility to extraneous stimuli, decreased persistence on a task because the task is not sufficiently reinforcing, or poor sensitivity to and recognition of significant environmental cues (Barkley, 1998). Although most cases develop before age seven, many individuals present with ADHD symptoms years earlier but the symptoms did not interfere with academic or social functioning. Children with ADHD have difficulty paying attention to and following conversations and instructions, staying on task, completing tasks, and inhibiting behavior in the face of seeking immediate gratification (Hinshaw & Zalecki, 2001). As a result, ADHD behaviors prove difficult to manage, resulting in academic difficulties and strained relationships with parents, teachers, and peers. Hyperactive-impulsive behavior typically emerges during the preschool years, although gross motor restlessness decreases

and inattention increases during childhood. Therefore, the Hyperactive-Impulsive subtype seems to be a developmental precursor to the Combined subtype (Barkley, 1997). Inattentive features related to the Inattentive subtype seem to have a later onset than the Hyperactive-Impulsive and Combined subtypes (Barkley, 1997). Childhood ADHD features and impairments frequently carry over into adulthood, such that problems with impulsivity and inattention continue; visible motoric restlessness and overactivity decrease while subjective restlessness and fidgetiness persist (Barkley, 1998; Hinshaw & Zalecki, 2001). The negative consequences of ADHD symptomatology are cumulative: ADHD is associated with greater risk for low academic achievement, poor peer and family relations, mental disorders (e.g., anxiety and depression), conduct problems, early substance use and abuse, driving accidents and speeding violations, and difficulties in adult friendships, marriages, and employment (Barkley, 1997).

Empirical evidence supports the validity of ADHD as a clinical phenomenon, despite media influences and popular culture impressions to the contrary (Barkley et al., 2002). However, professionals have debated the true nature and underlying mechanisms of ADHD and its subtypes (Barkley, 1998; Hinshaw & Zalecki, 2001). Barkley (1997) developed a model of ADHD to address these concerns, proposing that ADHD-H and ADHD-C differ categorically from ADHD-I. He posits that poor behavioral inhibition is the primary deficit in the Hyperactive-Impulsive and Combined subtypes, whereas poor information processing is the central deficit in the Inattentive subtype. In effect, Barkley differentiated the Hyperactive-Impulsive and Combined subtypes from the Inattentive subtype in terms of executive functions (behavioral inhibition and cognitive information processing, respectively). In ADHD-H and ADHD-C, behavioral disinhibition manifests

as hyperactivity and impulsivity, resulting in distractibility and poor sustained attention (vigilance). In ADHD-I, a cognitive information processing deficit manifests as slow cognitive tempo, resulting in distractibility and poor focused attention. Despite the proposed difference in underlying executive functions, all three subtypes involve distractibility and thus share a deficit in attentional processing.

Attention is a multidimensional construct that can refer to alertness, focused attention, sustained attention, or distractibility (Barkley, 1998). Similarly, ADHD is a multidimensional construct—consisting of symptoms of inattention, hyperactivity, and response disinhibition, as well as sequelae such as oppositional behavior, poor social skills, and academic failure—to the degree that professionals debate the very conceptualization of the three ADHD subtypes (e.g, Hinshaw & Zalecki, 2001). Nevertheless, the behavioral presentations of all three ADHD subtypes lead to the shared functional consequence of inattention, which allows ADHD to be conceptualized as a disorder of attentional processing.

The Continuous Performance Test

Symptoms of ADHD are most commonly assessed using the clinical interview, rating scales, and a medical evaluation (Barkley, 1998). However, laboratory measures designed to measure attention and impulsivity are becoming increasingly endorsed as assessment devices (e.g., Barkley, 1998; Riccio, Reynolds, & Lowe, 2001). One of the most popular laboratory measures is the Continuous Performance Test (CPT). In general, CPTs require participants to maintain vigilance and react to the presence or absence of a specific stimulus within a set of continuously presented distracters. One of the most popular commercial CPTs is the *Conners' Continuous Performance Test II* (CCPT;

Conners & MHS Staff, 2002). The CCPT is a computerized visual vigilance task that requires the individual to press the spacebar for every letter presented except the letter X.

The CCPT is widely used as a measure for diagnosing ADHD in children and adults (Conners and MHS Staff, 2002; Riccio et al., 2001). However, current research has produced equivocal results regarding the diagnostic utility of CPTs, including the CCPT (Barkley, 1998; Epstein, Conners, Sitarenios, & Erhardt, 1998; Riccio et al., 2001; Roy-Byrne et al., 1997; Solanto, Etefia, & Marks, 2004). Inconsistent results abound in both child and adult studies of CPT performance due to the existence of multiple CPT paradigms as well as the varying research methodologies employed to examine them (Epstein et al., 1998; Solanto et al., 2004). Whereas there has been extensive literature examining CPT performance in children, there is a dearth of research concerning CPT performance in adults (Epstein et al., 1998; Riccio et al., 2001; Solanto et al., 2004). In general, across child and adult samples, CPTs may be able to identify disorders characterized by difficulties with attention and impulsivity, but they cannot differentiate among these disorders (Riccio et al., 2001). Regarding CCPT performance in adults, studies report weak sensitivity and moderate specificity (e.g., Riccio et al., 2001; Epstein et al., 1998; Solanto et al., 2004). *Sensitivity* refers to the ability of a diagnostic measure to detect a disorder when it is present; for example, when individuals with ADHD perform poorly on a CPT compared to individuals without ADHD. *Specificity*, the natural complement of sensitivity, refers to the ability of a measure to detect the absence of a disorder when it is not present; for instance, when individuals without ADHD perform well on a CPT compared to individuals with ADHD. A high degree of specificity requires

that a diagnostic measure be able to differentiate among conditions, especially those with overlapping symptoms.

Overall, CPTs exhibit moderate strength in detecting the absence of attentional and impulsive difficulties, but weakness in differentiating among disorders associated with such difficulties (Epstein et al., 1998; Riccio et al., 2001; Solanto et al., 2004). Thus, CPTs are better at detecting normality than at differentiating psychopathology. Although the CCPT may provide some utility for helping to diagnose ADHD, there currently exists no gold standard measure for making a differential diagnosis of ADHD.

Focus of the Current Study

In the continuing search to discover a more accurate measure for diagnosing ADHD, it is appropriate to consider the phenomenon of change blindness. ADHD can be characterized as a disorder of attentional processing, and attentional processes have been shown to mediate change blindness (Mitroff & Simons, 2002; Rensink et al., 1997; Simons, 2000). Also, research has demonstrated the ecological validity of change blindness, such that change blindness has been demonstrated during a computerized flicker task as well as during a real-world occlusion event (Rensink et al., 1997; Simons & Levin, 1998). For example, Simons and Levin (1998) demonstrated that change blindness for central objects can occur in the real world. In their study, an experimenter approached the subject to ask for directions. Two other individuals proceeded to interrupt the conversation by carrying a door between the experimenter and the subject. During the occlusion, a second experimenter replaced the first experimenter. Only 50% of subjects detected this change, even though the two experimenters wore different clothing, were of different heights and builds, had different haircuts, and had different voices.

Building upon the established ecological validity of change blindness as a phenomenon, the use of environmentally realistic stimuli in the flicker task (photographs of real-world scenes) may offer superior ecological validity than the stimuli in the CCPT (the presentation of letters), which may provide improved diagnostic utility of the flicker task compared to the CCPT. Thus far, change blindness research has been restricted to establishing the robust nature of the phenomenon itself. Few studies have applied the implications of change blindness to a clinical population (e.g., Jones, Jones, Smith, & Copley, 2003; Mulfinger, 2005; Wheeler, 2005). However, the central role of attention in change blindness provided impetus in the present study for investigating this phenomenon in individuals with ADHD.

The current study examined the ability of the flicker task to serve as a more diagnostically accurate measure of ADHD than the CCPT. Flicker task and CCPT performance was compared between the ADHD and control group. Parallel dependent measures were used for the two tasks: the number of cycles needed to detect change, variability of cycles, and accuracy for the flicker task; and reaction time, variability of reaction time, and accuracy for the CCPT. For the flicker task, diagnostic group differences were predicted: the mixture of executive functioning deficits of the ADHD group was predicted to produce a greater number of cycles, greater variability of cycles, and lower accuracy compared to the control group. A within-subjects main effect of central and marginal changes was also predicted, with the expectation to replicate previous findings of faster identification of central than marginal changes (i.e., Rensink et al, 1997). For the CCPT, diagnostic group differences were predicted. Most studies on the diagnostic utility of the CCPT have shown poorer performance in adults with ADHD

compared with normal controls with respect to omission and commission errors (Epstein et al., 1998; Murphy, Barkley, & Bush, 2001; Walker, Shores, Trollor, Lee, & Sachdev, 2000) and variability of reaction time (Murphy et al., 2001; Walker et al., 2000). Similar predictions were made presently.

Flicker task and CCPT performance was compared to determine which task generates better diagnostic sensitivity and specificity. Compared to CCPT performance, flicker task performance was expected to generate better diagnostic sensitivity and specificity, consistent with the above hypothesis that the flicker task may provide better ecological validity than the CCPT.

The relationship of dependent measures among the flicker task, CCPT, and ADHD self-report ratings scales was examined. Ratings scale results were expected to correlate with flicker task number of cycles but not with CCPT reaction time, and with variability and accuracy for both tasks. Based on the respective cognitive and behavioral inhibition deficits of the three ADHD subtypes, elevated ratings of attention problems and hyperactivity were expected to be associated with greater number of cycles (slower detection) on the flicker task. CCPT research suggests that children and adults with ADHD do not differ in reaction time compared to individuals without ADHD (Epstein et al., 1998; Murphy et al., 2001; Roy-Byrne et al., 1997; Solanto et al., 2004; Walker et al., 2000). Thus, rating scale scores were not hypothesized to correlate with reaction time. Elevated ratings of both attentional problems and hyperactivity/impulsivity were expected to be associated with greater variability. Clinical assumptions have fostered various CPT-behavior links—omission errors reflect attention problems and commission errors reflect hyperactivity and impulsivity—although research attempting to confirm

these relationships has generated weak and conflicting results (Epstein et al., 1998; Epstein et al., 2003; Solanto et al., 2004). Consistent with research that has examined these assumed relationships, elevated ratings of attention problems were expected to correlate with increased omission errors, and elevated ratings of hyperactivity and impulsivity were expected to correlate with increased commission errors.

METHOD

Participants

Participants were recruited primarily by publicizing in psychology classes at Auburn University. Further recruitment of participants with ADHD occurred through the university's disabilities office and medical clinic, and through the offices of local physicians and psychologists. An age range criteria of 19-25 was established to minimize heterogeneity. The Auburn University Institutional Review Board approved the study.

Two-hundred and seventy-nine individuals were screened for inclusion in the ADHD and control group by using a demographic questionnaire (see Appendix A) and the Conners' Adult ADHD Rating Scale-Self-Report, Long Form (CAARS; Conners, Erhardt, & Sparrow, 1999), a norm-referenced diagnostic questionnaire based on DSM-IV ADHD criteria. Inclusion criteria for the ADHD group required that individuals: (a) endorse a current ADHD diagnosis, with or without past or current use of psychostimulant medication; and (b) complete the CAARS such that scores exceeded 1.5 standard deviations above the mean for the *DSM-IV Inattentive Symptoms Scale* and/or the *DSM-IV Hyperactive-Impulsive Symptoms Scale*. Individuals with current or past use of psychostimulant medication for ADHD were instructed to respond to the CAARS regarding their off-medication behavior. Respondents were excluded if they reported

current use of any other psychoactive medication. However, individuals with ADHD were not excluded based on past or current history of other psychological disorders.

Inclusion criteria for the control group required that individuals: (a) deny past or current history of an established ADHD diagnosis; (b) complete the CAARS, such that scores did not exceed 1 standard deviation above the mean for the *DSM-IV Inattentive Symptoms Scale* and/or the *DSM-IV Hyperactive-Impulsive Symptoms Scale*; and (c) deny current use of any psychoactive medication. Similar to the ADHD group, individuals from the control group were not excluded based on past or current history of psychological disorders.

Twenty-eight individuals with ADHD and 30 individuals without ADHD met study criteria and completed the study. Of the 28 individuals with ADHD, 15 met CAARS criteria for ADHD-I, 1 for ADHD-H, and 12 for ADHD-C. Participants were matched as best as possible for sex and age. The ADHD group included 9 males and 19 females, with a mean age of 20.46 years (SD = 1.71); the control group included 9 males and 21 females, with a mean age of 20.40 years (SD = 1.38). The majority of participants in both groups were Caucasian. There was no difference in age or proportion of race and sex between the ADHD and control group, or between the three ADHD subtypes. Of the 28 individuals with ADHD, 24 reported current use of ADHD medication: 13 (46.4%) reported using Adderall, 8 (28.6%) using Adderall XR, 4 (14.3%) using Ritalin, 2 (7.1%) using Concerta, 1 (3.6%) using Ritalin LA, and 1 (3.6%) using Dextrostat. Total *n* and percentage sum to greater than 24 and 100%, respectively, because 5 of the 24 individuals with ADHD reported using two ADHD medications. Mean CAARS responses of the diagnostic groups differed significantly for all scales, such that

individuals with ADHD reported greater ADHD symptoms and related difficulties (see Table 1). Participants were recruited by various methods: 45 (77.6%) via departmental publicity, 7 (12.1%) via local health care providers, 3 (5.2%) via friends, and 3 (5.2%) via the principal investigator.

Table 1. CAARS Scores and Group Comparison.

	ADHD Group (n = 28)		Control Group (n = 30)		
Scale	*M*	(*SD*)	*M*	(*SD*)	*F*
Inattention/memory problems	66.00	(11.16)	44.87	(6.06)	81.78*
Hyperactivity/restlessness	62.29	(9.65)	44.67	(8.30)	55.80*
Impulsivity/emotional lability	59.68	(12.58)	43.37	(7.76)	35.86*
Problems with self-concept	53.82	(9.48)	43.60	(6.07)	24.23*
DSM-IV inattention symptoms	75.61	(8.23)	47.23	(6.11)	224.07*
DSM-IV hyp-imp symptoms	64.36	(10.66)	43.73	(7.62)	72.56*
DSM-IV ADHD symptoms total	73.64	(9.17)	45.40	(6.85)	178.14*
ADHD index	62.29	(8.83)	43.70	(7.07)	78.87*

Note. CAARS = Conners' Adult ADHD Rating Scales; ADHD = Attention-Deficit/Hyperactivity Disorder; DSM = *Diagnostic and Statistical Manual of Mental Disorders*; hyp-imp = hyperactive/impulsive. All scores refer to T-scores.
*$p < .001$.

Measures

CAARS. The CAARS assesses core symptoms of ADHD and related problems in adults 18 years of age and older. The psychometric properties of the instrument are described in the manual (Conners et al., 1999). The long form has 66 items and 8 subscales. Raw scores on each scale are converted to T-scores based on norms for sex and 10-year age intervals obtained from a sample of 839 normal adults. Factor analysis applied to the standardization sample yielded a four-factor solution (Inattention/Memory Problems; Hyperactivity/Restlessness; Impulsivity/Emotional Lability; Problems with Self-Concept). The other four scales correspond to the ADHD Index, and the DSM-IV

symptom list for Inattention, Hyperactivity-Impulsivity, and Total ADHD. Internal reliability coefficients for the subscales in the normative sample ranged from .88-.91 across groups and scales. Discriminant validity was assessed on a sample of 39 adults with ADHD and 39 non-clinical adults, yielding a highly significant group difference in mean raw score (25.66 versus 10.49, respectively, SD = 7.92). Overall correct classification rate was 85%. Conners et al. (1999) did not report sensitivity and specificity.

Flicker task. E-Prime software was used to present stimuli on a PC desktop computer (17 in (43.18 cm) monitor, 1,024 x 768 resolution, 75 Hz refresh rate). Flicker sequences included an original image A, a modified image A', and a gray blank field /. The images were displayed in the sequence A / A' / A / A' and so on, such that a gray blank field was placed between successive images. Each image displayed for 240 ms and each blank for 80 ms. The present study included the set of 48 item-pair digitized photographs (each 24.7 x 17.6 cm) of real-world scenes used by Rensink et al. (1997). Six item-pairs comprised the trial set, and 42 item-pairs comprised the stimuli set. Each item-pair contained a single change of presence/absence, color, or location made to an object or area; each change was of either central or marginal interest. Overall, the stimulus set contained central and marginal interest subsets of 21 item-pairs each, with each subset containing seven instances of changes in presence/absence, color, and location. Item-pairs were presented in random order for each participant. Of note, Rensink et al. established a 1 min time limit, but did not report any instances of failure to identify a change (omission error). However, pilot testing in the present study indicated a trend toward a considerable number of omission errors. Thus, a 2 min time limit was

established to reduce any frustration experienced by inability to detect the change. Duration of task administration was approximately 10 to 15 min, depending on participant performance.

CCPT. The CCPT was administered on a PC laptop computer (15 in (38.10 cm) monitor, 1,024 x 768 resolution), using the standard protocol offered by the software (Conners & MHS Staff, 2002). Three-hundred and sixty letters (approximately 1 in high) appeared on screen, one at a time, for approximately 250 ms. The 360 trials were presented in 18 consecutive blocks of 20 trials, with each block using one of three interstimulus interval (ISI) conditions (1, 2, or 4 s). The ISI conditions were block-randomized across the 18 blocks, such that all three ISI conditions occurred every three blocks. In this manner, the protocol was divided into six time blocks consisting of all three ISI conditions. Across ISI and time blocks, the percentage of trials in which letters other than X appeared was 90%. Duration of task administration was 14 min.

Independent Measures

Between-Group. For both the flicker task and CCPT, diagnostic group (ADHD versus control group) served as a between-group independent measure.

Within-Subjects. For the flicker task only, degree of interest (central and marginal) and change type (presence/absence, color, location) served as within-subjects independent measures.

Dependent Measures

Flicker Task. Mean number of cycles needed to detect change, variability (standard deviation) of mean number of cycles, and accuracy served as dependent measures. Mean number of cycles was calculated for: the average across all stimuli; the

levels of degree of interest (central and marginal); the levels of change type (presence/absence, color, and location); and the six stimulus types resulting from crossing the levels of degree of interest by change type. Variability was defined as: the respective standard deviations for the abovementioned means; the change in cycles across the duration of the test (generated by dividing the flicker task into six blocks of seven item-pairs, to mirror the CCPT time block organization, and calculating means and standard deviations per time block); the change in accuracy across the duration of the test (generated by calculating the means and standard deviations of errors per time block). Accuracy was defined as: the failure to identify a change (omission error); and the incorrect identification of a change (commission error). Accuracy also served as a manipulation check to ensure that participants did not falsely report having detected the change. Averages and standard deviations for mean number and variability of cycles excluded incorrect responses.

CCPT. This task provides a host of diagnostic variables for which norms exist. Twelve of these variables were placed into dependent measure groups of reaction time, variability of reaction time, and accuracy; a 13th variable of Confidence Index also served as a dependent measure. The only reaction-time dependent measure was the average speed of correct responses for the entire test (Hit RT). Variability dependent measures included: the standard error of Hit RT (Hit RT SE); a measure of "within-respondent" variability, which compared the variability of 18 time blocks to the overall variability, Hit RT SE (Variability); the change in reaction time across the duration of the test (Hit RT Block Change) and its associated standard error (Hit SE Block Change); the change in mean reaction time for the different ISIs of 1, 2, and 4 s (Hit RT ISI Change) and its

associated standard error (Hit SE ISI Change); and an indicator of either unusually slow, random, or anticipatory responding, or repeated responding without consideration of the stimuli or task requirements (Perseverations). Accuracy dependent measures included: the failure to respond to target (non-X) letters (Omission Error); the response to non-target (X) letters (Commission Error); the discriminative power to differentiate between the signal (non-X) and noise (X) distributions (Detectability, d'); and the response tendency to be overly or less concerned about mistakenly responding to non-targets (Response Style, B). The Confidence Index is a discriminant function indicating if the overall results better match a clinical or non-clinical profile.

Procedure

Prior to participation in the test session, individuals completed a screening packet containing an informed consent form, a demographic and contact information sheet (including a form requiring self-report or denial of an established ADHD diagnosis), and the CAARS. Individuals meeting study criteria were contacted to schedule a test session.

The flicker task and CCPT were administered during a single, 1 hr test session, using a counterbalanced order of administration. By precedent, participants sat comfortably without head restraint approximately 50 cm from the monitor. Testing took place in a well-lighted room free of distraction; white noise was used to attenuate any external sound. The primary investigator remained in the room during testing, seated approximately 10 ft behind the participant, to ensure proper task administration. To participate in the test session, participants with ADHD currently taking medication for ADHD consented to undergo a 24-hour medication washout period prior to the computer test session, and verbally confirmed adherence to this procedure at the time of testing.

For the flicker task, participants read on-screen instructions (see Appendix B) that a change may occur to an image and that the change type would consist of presence/absence, color, or location. Participants were instructed to press the spacebar key when they detected the change, and then to report the change. Prior to the test phase, participants paraphrased the instructions (to ensure understanding of the task) and completed six practice trials to familiarize themselves with the task. For the CCPT, participants read on-screen instructions (see Appendix C) to press the spacebar for every letter presented except the letter X. Prior to the test phase, participants paraphrased the instructions and completed the 2 min practice administration.

Participants received extra credit in a psychology course for completing the screening packet. In addition, participants who completed the computer test session received the choice of $5 or extra credit in a psychology course, and were eligible to win one of two $50 cash prizes (one per diagnostic group).

RESULTS

Between-Group and Within-Subjects Differences

Flicker Task. Prior to running analyses, the mean number of cycles was calculated for each flicker task item-pair, and outlier responses were recoded as the number of cycles immediately below three standard deviations above the mean of the respective item-pair. Outlier rates were low, averaging 3.20% across all item-pairs, and did not differ by diagnostic group.

To examine flicker task performance (see Table 2), a 2 (diagnostic group) x 2 (degree of interest) x 3 (change type) mixed-design ANOVA was conducted for mean number of cycles needed to detect change. There was a significant main effect of degree

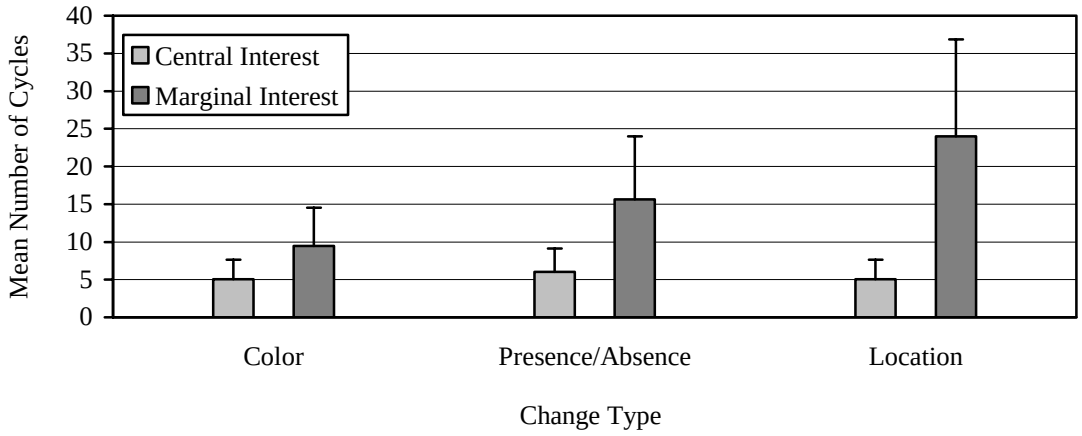
Table 2. Group Performance on Flicker Task Measures.

	ADHD Group (n = 28)		Control Group (n = 30)	
Measure	*M*	(*SD*)	*M*	(*SD*)
	Mean number of cycles			
Degree of interest				
Central	5.86	(2.18)	4.93	(1.86)
Marginal	15.48	(8.03)	16.58	(5.91)
Change type				
Color	7.27	(3.47)	7.21	(2.45)
Presence/absence	10.38	(5.92)	10.84	(4.77)
Location	13.64	(7.32)	13.86	(5.59)
	Variability of mean number of cycles			
Degree of interest				
Central	6.05	(3.50)	4.58	(3.23)
Marginal	16.18	(8.52)	18.45	(9.69)
Change type				
Color	7.14	(4.46)	7.86	(4.94)
Presence/absence	9.82	(7.91)	13.25	(8.40)
Location	17.21	(9.79)	18.30	(11.24)

Note: ADHD = Attention-Deficit/Hyperactivity Disorder.

of interest, $F(1, 56) = 185.80$, $p < .001$, consistent with results from and using the same stimuli as Rensink et al. (1997). Participants more rapidly detected central than marginal changes (M = 5.38 cycles [3.49 s], SD = 2.06; M = 16.05 cycles [10.61 s], SD = 6.97; respectively). There was also a significant main effect of change type, $F(2, 112) = 50.31$, $p < .001$. Pairwise comparisons revealed that mean number of cycles differed for each change type ($p < .001$), with cycles increasing in the following order of change type: color, presence/absence, and location (M = 7.24 [4.70 s], SD = 2.96; M = 10.62 [6.89 s], SD = 5.31; M = 13.75 [8.92 s], SD = 6.42, respectively). However, there was a significant interaction between degree of interest and change type, $F(2, 114) = 63.90$, $p < .001$ (see Figure 2). Comparison of the cell means revealed a significant difference of detecting

Figure 2. Mean number of cycles needed to detect change plotted by flicker task change type and degree of interest.

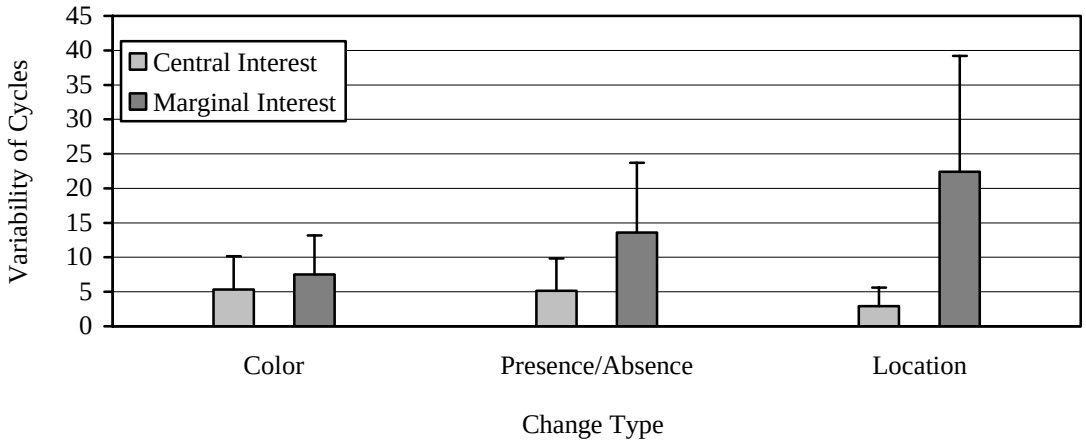


central interest changes across change type ($p < .04$), such that the number of cycles for the change type of presence/absence ($M = 6.04$ [3.92 s], $SD = 3.00$) was greater (albeit minimally) than that of color and location ($M = 5.05$ [3.27 s], $SD = 2.25$; $M = 5.06$ [3.28 s], $SD = 3.03$, respectively). In contrast, a significant difference of detecting marginal interest changes across change type was found ($p < .001$), such that the number of cycles differed for each change type, with number of cycles increasing in an order identical to that found for the main effect of change type: color, presence/absence, and location ($M = 9.45$ [6.13 s], $SD = 5.02$; $M = 15.63$ [10.14 s], $SD = 9.15$; $M = 24.00$ [15.57 s], $SD = 11.81$, respectively). There were no other significant main or interaction effects.

Also with respect to flicker task performance (see Table 2), a 2 (diagnostic group) x 2 (degree of interest) x 3 (change type) mixed-design ANOVA was conducted for variability of cycles involved in detecting change. There was a significant main effect of degree of interest, $F(1, 56) = 96.28$, $p < .001$. Participants exhibited greater variability for marginal than central changes ($M = 17.35$ cycles [11.25 s], $SD = 9.14$; $M = 5.29$ cycles [3.43 s], $SD = 3.41$; respectively). There was also a significant main effect of change

type, $F(2, 112) = 20.16$, $p < .001$. Pairwise comparisons revealed that variability of cycles differed for each change type ($p < .005$), with variability increasing in the following order of change type: color, presence/absence, and location ($M = 7.51$ [4.87 s], $SD = 4.69$; $M = 11.60$ [7.52 s], $SD = 8.27$; $M = 17.77$ [11.52 s], $SD = 10.49$, respectively). However, there was a significant interaction between degree of interest by change type, $F(2, 114) = 46.97$, $p < .001$ (see Figure 3). Comparison of the cell means revealed a significant difference of detecting central interest changes across change type ($p < .002$), such that only the variability of cycles for the change type of location ($M = 2.94$ [1.91 s], $SD = 2.56$) was less than that of presence/absence and color ($M = 5.14$ [3.33 s], $SD = 4.97$; $M = 5.32$ [3.45 s], $SD = 4.81$, respectively). In contrast, a significant difference of detecting marginal interest changes across change type was found ($p < .001$), such that the variability of cycles differed for each change type, with number of cycles increasing in an order identical to that found for the main effect of change type: color, presence/absence, and location ($M = 7.53$ [4.88 s], $SD = 5.99$; $M = 13.57$ [8.80 s], $SD = 11.13$; $M = 22.42$

Figure 3. Variability of mean number of cycles involved in detecting change plotted by flicker task change type and degree of interest.



[11.54 s], *SD* = 14.08, respectively). Also, there was a marginal interaction between diagnostic group and degree of interest, $F(1, 56) = 3.91$, $p = .053$. Independent samples *t* tests revealed that the ADHD group had marginally greater variability for central interest changes compared to the control group, $t(1, 56) = 1.66$, $p = .102$ (*M* = 6.05 cycles [3.92 s], *SD* = 3.50; *M* = 4.58 cycles [2.97 s], *SD* = 3.22, respectively). No difference for marginal interest changes was found between the ADHD and control group, $t(1, 56) = 0.94$, $p = .350$ (*M* = 16.18 cycles [10.69 s], *SD* = 8.51; *M* = 18.45 cycles [11.97 s], *SD* = 9.69, respectively). There were no other significant main or interaction effects.

To examine flicker task performance over time, a 2 (diagnostic group) x 6 (time block) mixed-design ANOVA was conducted separately for mean number of cycles and variability of cycles needed to detect change. There were no significant main or interaction effects: the mean number of cycles (see Figure 4) and variability of cycles (see Figure 5) needed to detect change did not differ by diagnostic group or by time block.

To examine accuracy, independent-samples *t* tests were conducted separately for commission and omission errors. There was a significant main effect of commission errors, $t(1, 56) = 3.46$, $p = .001$, such that participants with ADHD committed more commission errors than did controls (*M* = 3.00, *SD* = 2.16; *M* = 1.23, *SD* = 1.72, respectively). There was no main effect of omission errors (ADHD: *M* = 0.32, *SD* = 0.82; Controls: *M* = 0.30, *SD* = 0.47).

Figure 4. Mean number of cycles needed to detect change plotted by flicker task time block.

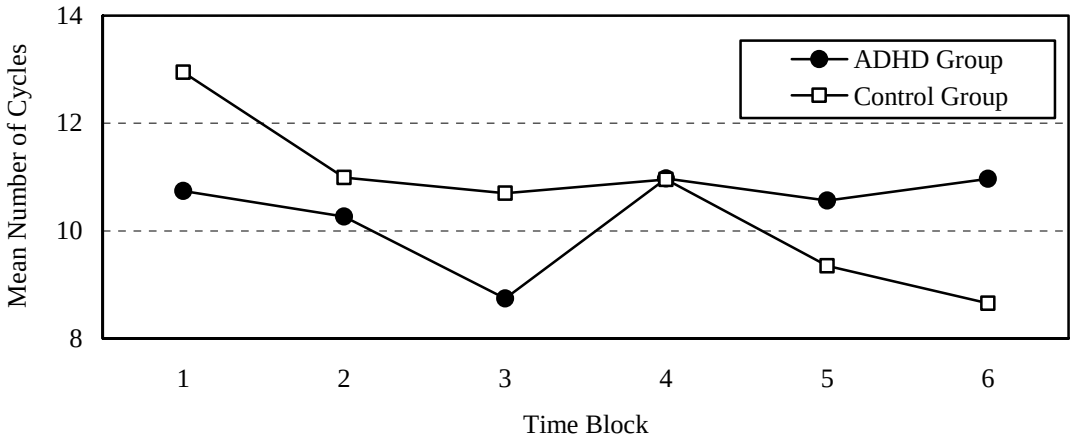
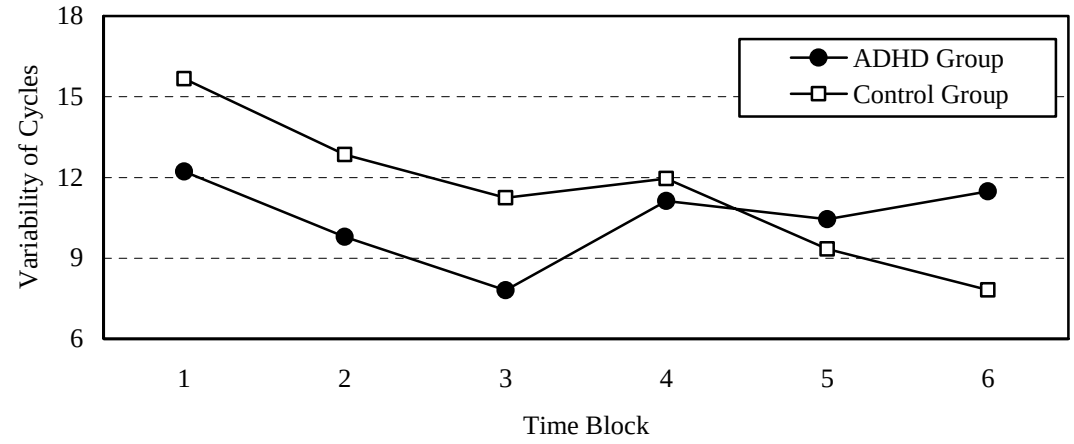


Figure 5. Variability of mean number of cycles involved in detecting change plotted by flicker task time block.



To examine accuracy over time, 2 (diagnostic group) x 6 (time block) mixed-design ANOVAs were conducted separately for commission and omission errors. There was a main effect of time block for both commission errors, $F(5, 280) = 3.08$, $p = .010$ (see Figure 6), and omission errors, $F(5, 280) = 2.92$, $p = .046$ (see Figure 7), such that accuracy varied across the six time blocks. Secondary ANOVAs were conducted, using two instead of six time blocks, to gain a more direct understanding of how accuracy

Figure 6. Commission errors plotted by flicker task time block.

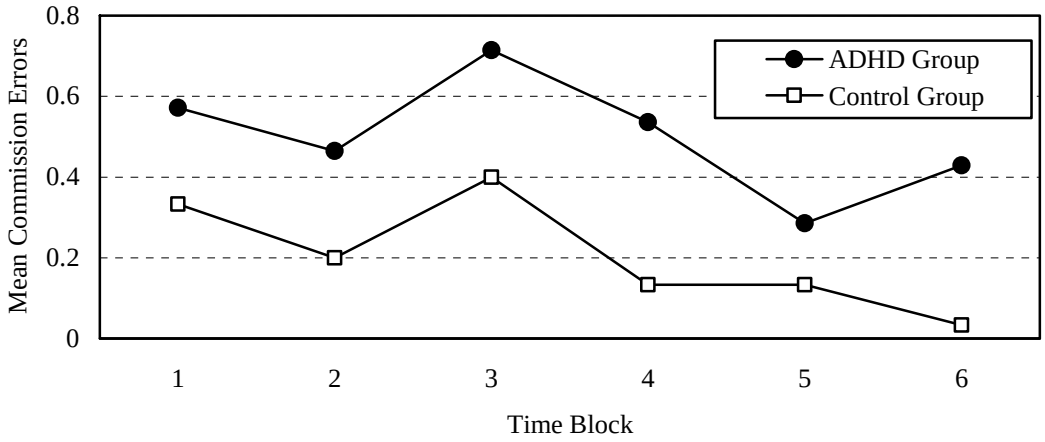
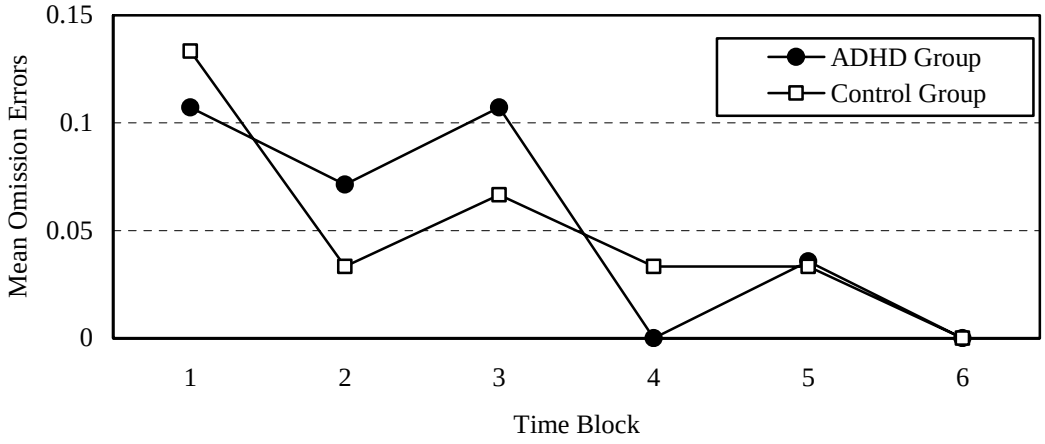


Figure 7. Omission errors plotted by flicker task time block.



varied over time. That is, 2 (diagnostic group) x 2 (time block) mixed-design ANOVAs were conducted separately for commission and omission errors. There was a main effect of time block for both commission errors, $F(1, 56) = 8.54$, $p = .005$ (see Figure 8), and omission errors, $F(1, 56) = 7.25$, $p = .009$ (see Figure 9). Participants made a greater number of commission and omission errors in the first half compared to the second half of the flicker task. There were no other significant main or interaction effects.

Figure 8. Commission errors plotted by flicker task time block.

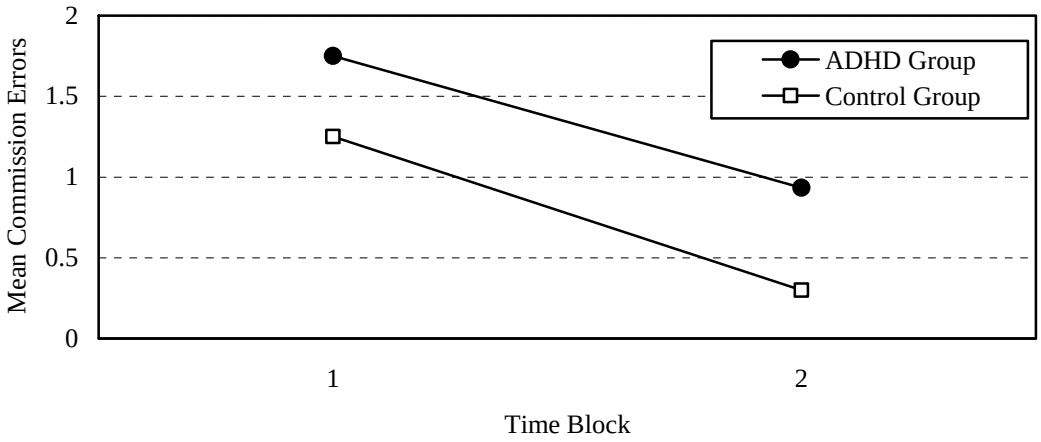
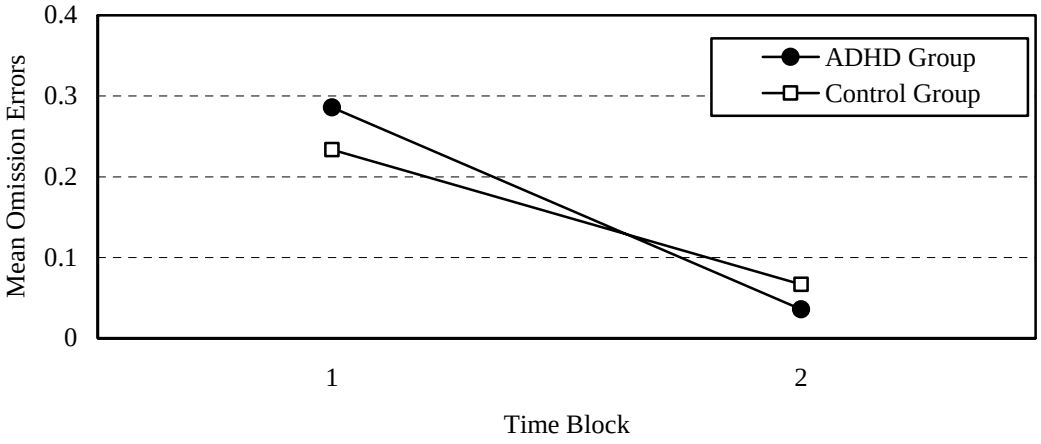


Figure 9. Omission errors plotted by flicker task time block.



CCPT. A MANOVA was conducted to test mean differences between the ADHD and control group for the CCPT dependent measures. There was a significant main effect of diagnostic group, $F(13, 44) = 2.05$, $p = .039$. The mean raw (Confidence Index only) and T-scores for all dependent measures were in the non-clinical range (see Table 3). Participants with ADHD had higher commission error rates than did controls, $F(1, 56) = 9.39$, $p = .003$. Participants with ADHD had higher detectability T-scores than did control participants, $F(1, 56) = 10.60$, $p = .002$, suggesting a less sensitive threshold to stimulus

Table 3. Group Performance on CCPT Measures.

	ADHD Group (n = 28)		Control Group (n = 30)			
Measure	*M*	(*SD*)	*M*	(*SD*)	*F*	*p*
			Reaction time			
Hit RT	44.61	(9.41)	41.75	(8.6)	1.45	.234
			Variability			
Hit RT SE	50.94	(11.06)	43.69	(8.60)	7.82	.007
Variability	50.60	(8.82)	46.18	(8.35)	3.84	.055
Hit RT block change	46.39	(14.28)	47.99	(6.72)	.30	.583
Hit SE block change	52.26	(10.57)	52.29	(8.93)	.00	.991
Hit RT ISI change	55.00	(12.06)	49.50	(7.11)	4.55	.037
Hit SE ISI change	52.95	(10.84)	49.63	(7.72)	1.83	.181
Perseverations	51.92	(12.51)	48.88	(5.62)	1.46	.232
			Accuracy			
Omissions errors	48.43	(6.40)	48.77	(14.41)	.01	.910
Commissions errors	56.58	(10.75)	48.67	(8.89)	9.39	.003
Detectability (d')	56.11	(8.52)	48.63	(8.94)	10.60	.002
Response style (B)	46.22	(2.41)	47.24	(4.69)	1.06	.308
			Overall profile (clinical vs. non-clinical)			
Confidence index	40.62	(20.89)	31.41	(18.90)	3.11	.083

Note. ADHD = Attention-Deficit/Hyperactivity Disorder; RT = reaction time; SE = standard error; ISI = interstimulus interval. All scores except Confidence Index (raw) refer to T-scores.

events than for control participants. Participants with ADHD had greater variability of mean reaction time, $F(1, 56) = 7.82$, $p = .007$, and greater variability in mean reaction time for the different ISIs, $F(1, 56) = 4.55$, $p = .037$, compared to control participants. There was also a marginally significant result suggesting that participants with ADHD had greater "within-respondent" variability than did controls, $F(1, 56) = 3.84$, $p = .055$.

Correlations Between Flicker Task and CCPT Dependent Measures and CAARS Scores

Correlations between flicker task and CCPT dependent measures and CAARS scores were examined to determine if any dependent measure was differentially associated with inattention, hyperactivity/impulsivity, or total ADHD symptoms (see Table 4). Flicker task commission errors were significantly correlated with inattentive, hyperactivity/impulsivity, and total ADHD symptoms, indicating that increased commission errors reflected elevated ADHD symptomatology. A few other correlations between flicker task and CAARS scores were significant, but did not provide further interpretive clarity and therefore are not discussed. CCPT commission errors, HIT RT SE, and detectability were significantly correlated with inattentive, hyperactivity/impulsivity, and total ADHD symptoms, suggesting that increased commission errors, increased variability of mean reaction time, and lower sensitivity level to stimulus presentations reflected elevated ADHD symptomatology. Also, Hit SE ISI Change was significantly correlated with hyperactivity/impulsivity, indicating that increased variability of mean reaction time for the ISIs reflected elevated levels of

Table 4. Pearson Correlations Between Flicker Task and CCPT Dependent Measures and ADHD Symptomatology.

	Flicker Task	CCPT			
Scale	Commission errors	Commission errors	Hit RT SE	Detectability (d')	Hit SE ISI change
DSM-IV inattentive	.350**	.356**	.318*	-.412**	.180
DSM-IV hyp/imp symptoms	.461**	.349**	.318*	-.406**	.283*
DSM-IV ADHD symptoms	.421**	.371**	.334*	-.430**	.238

Note. n = 58. CCPT = Conners' Continuous Performance Test; ADHD = Attention-Deficit/Hyperactivity Disorder; RT = reaction time; SE = standard error; ISI = interstimulus interval; hyp-imp = hyperactive/impulsive; All scores refer to raw scores.
*p < .05. **p < .01

hyperactive/impulsive symptoms. Correlations between parallel performance measures of the flicker task and CCPT were also examined to assess similarity of measured constructs (i.e., flicker task cycles/CCPT reaction time, variability, and accuracy). None of the correlations were significant (all *p*s > .05), except for the significant relationship between the accuracy measures of flicker task mean number of cycles needed to detect change for Time Block 4 and CCPT Detectability, $r = .27$, $p = .040$.

Diagnostic Utility

Flicker Task. To examine the utility of the flicker task in differentiating individuals with and without ADHD, only dependent measures that demonstrated statistically significant between-group differences (commission errors) were entered (using raw scores) as predictors in a forward stepwise logistic regression. Inclusion of dependent measures was based on an alpha of .05. Commission errors remained in the final equation and was associated with a Beta weight of 0.48; an estimated odds ratio of 1.61; and a Wald value of 8.56, $p = .003$. The resulting classification matrix correctly identified 16 of 28 members of the ADHD group, producing a sensitivity coefficient of 57%; and 26 of 30 members of the control group, producing a specificity coefficient of 87%. The overall correct classification rate was 72%. Positive and negative predictive power were 80% and 68%, respectively.

CCPT. To examine the diagnostic utility of the CCPT, dependent measures that demonstrated statistically significant between-group differences (detectability (d'), commissions errors, Hit RT SE, and Hit RT ISI change) were entered (using T-scores) as predictors in a forward stepwise logistic regression. Inclusion of dependent measures was based on an alpha of .05. Only Hit RT SE and detectability (d') remained in the final

equation and were associated, respectively, with a Beta weight of 0.09 and 0.13; an estimated odds ratio of 1.09 and 1.13; and a Wald value of 6.72, $p = .010$, and 7.45, $p = .006$. The resulting classification matrix correctly identified 20 of 28 members of the ADHD group, producing a sensitivity coefficient of 71%; and 23 of 30 members of the Control group, producing a specificity coefficient of 77%. The overall correct classification rate was 74%. Positive and negative predictive power were both 74%.

Combined tasks. The combined diagnostic utility of the flicker task and CCPT was examined. Dependent measures from the flicker task and CCPT that demonstrated statistically significant between-group differences (as noted above) were entered (using raw and T-scores, respectively) as predictors in a forward stepwise logistic regression. Inclusion of dependent measures was based on an alpha of .05. Only the flicker task dependent measure of commission errors and the CCPT dependent measures of Hit RT SE and detectability (d') remained in the final equation and were associated, respectively, with a Beta weight of 0.49, 0.10, and 0.12; an estimated odds ratio of 1.63, 1.11, and 1.12; and a Wald value of 6.83, $p = .009$, 6.55, $p = .010$, and 5.50, $p = .019$. The resulting classification matrix correctly identified 21 of 28 members of the ADHD group, producing a sensitivity coefficient of 75%; and 24 of 30 members of the Control group, producing a specificity coefficient of 80%. The overall correct classification rate was 78%. Positive and negative predictive power was 78% and 77%, respectively.

DISCUSSION

Contrary to current prediction, the flicker task does not demonstrate better diagnostic utility compared to the CCPT. Instead, both measures provide insufficient diagnostic utility. Current CCPT sensitivity (71%) appears to be an improvement over

results from prior CCPT studies, although specificity (77%) is similar to past studies, with Epstein et al. (1998) reporting sensitivity and specificity of 55% and 76.4%, respectively, and Solanto et al. (2004) reporting sensitivity and specificity (for only the ADHD-I group) of 47% and 86%, respectively. The seeming improvement in CCPT sensitivity, but not specificity, may be due in part to the increased homogeneity of the current sample compared to those used in the above two CCPT studies. Increased sample homogeneity may have yielded an ADHD group with relatively uniform attentional difficulties, thereby enhancing the ability of the CCPT to detect abnormal performance from the ADHD group, that is, sensitivity. In contrast, it is unlikely that increased sample homogeneity would increase the uniformity of attention in the control group or enhance the ability of the CCPT to detect normal performance in a normal sample. Therefore, an improvement in specificity reported in prior studies would not be expected, especially given that specificity has been relatively high in past CCPT studies. Flicker task sensitivity (57%) and specificity (87%) are similar to results from past CCPT studies, but are inferior and superior, respectively, compared to current CCPT results. However, current overall correct classification for the flicker task and CCPT is similar (72% and 74%, respectively). Consistent with prior research, sensitivity, specificity, and overall correct classification of these measures do not support their utility in discriminating adults with and without ADHD.

It should be noted that studies (including the present research) examining the CCPT have used various methods to determine diagnostic utility, such as using logistic regression or discriminant function analysis, examining between-group differences, or establishing an arbitrary cut-off score for a given dependent measure to ascribe abnormal

performance (e.g., Epstein et al., 1998; Solanto et al., 2004; Walker et al., 2000). Utilization of one method over another to determine diagnostic utility may serve to highlight the difference in goals regarding the understanding of ADHD. For example, researchers may use logistic regression to examine differences at the group level, whereas clinicians may use a criterion of 1.5 standard deviations above the mean to identify ADHD at the individual level. Researchers examining CCPT diagnostic utility have used "best-case" sensitivity and specificity analyses (e.g., using only significant between-group dependent measures), which may yield enhanced diagnostic utility compared to diagnostic software that accompanies a commercially available CPT (e.g., Epstein et al., 1998; Solanto et al., 2004). In general, the lack of uniformity in determining CCPT diagnostic utility suggests exercising caution when interpreting results.

Although the flicker task and the CCPT provide similarly insufficient diagnostic utility, further exploration of group performance provided additional information about the characteristics of these two measures. With respect to CCPT performance, consistent with current prediction, adults with ADHD demonstrated poorer accuracy (greater commission errors) and greater variability (increased variability of reaction time) compared to controls. Diagnostic group differences for commission errors and increased variability of reaction time are consistent with prior CCPT research (e.g., Epstein et al., 1998; Murphy et al., 2001; Walker et al., 2000). In addition, the ADHD group demonstrated poorer accuracy and greater variability on two other CCPT dependent measures (poorer detectability and increased variability of reaction time for the different ISI conditions, respectively) compared to controls. Contrary to current prediction, there was no diagnostic group difference for omission errors. Murphy et al. (2001) found that

the ADHD group made more CCPT omission errors than controls, but this difference did not hold when they held IQ constant. Although IQ was not controlled formally in the present study, at least 77% of participants were college students. The similar level of education may have served as an informal control for IQ, which, consistent with Murphy et al. (2001), may explain the lack of group differences for omission errors.

With respect to flicker task performance, participants detected more quickly central compared to marginal interest changes, which replicates findings from Rensink et al. (1997), Mulfinger (2005), and Wheeler (2005). Also, Rensink et al.'s (1997) findings were replicated in that detection of marginal interest changes took significantly longer than central interest changes for each change type. Rensink et al. (1997) did not compare performance between change types (presence/absence, color, location). However, such comparison in the present study revealed that observers detected different change types of marginal interest with variable facility (requiring increasing cycles to detect change in the order of color, presence/absence, and location), whereas they detected the different central interest change types with comparable ability. Future research on marginal interest change types may provide further insight regarding focused attention. For example, the variable facility in detecting the three different marginal interest change types may be specific to Rensink et al.'s (1997) stimuli. Replication of this finding with a different set of marginal interest stimuli would further support the idea that focused attention indeed operates differentially for marginal interest change types, whereas a finding of equal ability to detect marginal interest change types would suggest that focused attention operates similarly for both central and marginal interest change types. Overall, the replication and extension of Rensink et al.'s (1997) work provide further

support for the robust nature of the change blindness phenomenon and for using the flicker task to demonstrate this phenomenon.

Consistent with current prediction for flicker task performance, the ADHD group demonstrated lower accuracy (increased commission errors) compared to the control group. Inconsistent with current prediction, there was no group difference for omission errors. As cited above, the lack of group difference for omission errors may be due to the similar educational level in the present sample having served as an informal control for IQ (Murphy et al., 2001). Contrary to current hypotheses, there was no diagnostic group difference for mean number of cycles needed to detect change or variability of cycles. The lack of group difference in mean number of cycles is not surprising, given the absence of group differences regarding reaction time in the CCPT literature (Epstein et al., 1998; Murphy et al., 2001; Roy-Byrne et al., 1997; Solanto et al., 2004; Walker et al., 2000). In contrast, the lack of group difference in variability of cycles is noteworthy, given that CCPT studies have produced such differences (Murphy et al., 2001; Walker et al., 2000). However, a recent meta-analysis of the stop-signal CPT suggested that variability in reaction time (cycles for the flicker task) may be a hallmark of childhood ADHD, but not adult ADHD (Lijffijt, Kenemans, Verbaten, & van Engeland, 2005).

The flicker task is posited to be a measure of focused attention (Rensink et al., 1997; Simons, 2000), such that performance may be expected to fluctuate over time. However, performance did not vary by diagnostic group or time for any dependent measure except commission errors, which decreased across two time blocks for both groups. It is possible that the changes were not difficult enough to detect or that the number of stimuli was not sufficiently large to tax the mechanisms of focused attention.

The hypothesis that enhanced ecological validity of the flicker task compared to the CCPT would elicit diagnostic group differences was not supported. Instead, the increased realism of the flicker task stimuli may have reduced the attentional difficulties of the ADHD group, thereby enhancing performance of the ADHD group. Thus, the increased realism of the flicker task may have produced an effect similar to a study demonstrating that children with ADHD showed better attention to colorful or highly stimulating educational materials compared to less stimulating or uncolored materials (Barkley, 1990).

Flicker task and CCPT sensitivity and specificity are similar, despite the fact that the CCPT generated more between-group differences than did the flicker task. This disparity in between-group differences may suggest that adults with ADHD have greater difficulty with tasks of disinhibition compared to tasks of focused attention. Although a meta-analysis of the response inhibition stop-signal CPT showed that adults with ADHD demonstrate deficits in such a task (Lijffijt et al., 2005), adults with ADHD do not consistently show deficits across other types of response inhibition tasks (Epstein et al., 2001). Similarly, it may be possible that adults with ADHD do not show a great number of deficits on various types of focused attention tasks, such as the flicker task. The similar sensitivity and specificity of the flicker task and CCPT also provide a strong counterargument to the notion that adults with ADHD demonstrated greater difficulty on the CCPT compared to the flicker task. Instead, the disparity in between-group differences may be due to differential task demands in that the CCPT is a response inhibition (go/no go) task, whereas the flicker task is a focused attention (go) task. Virtually all commercially available CPTs or those used in research studies are variants

of the response inhibition paradigm (Riccio et al., 2001). Therefore, future studies may include CPTs that isolate mechanisms of focused attention—e.g., "go" serial search tasks such as the flicker task—which will allow comparison of between-group differences for go and go/no go CPTs. In terms of diagnostic utility and between-group differences, it is doubtful that a CPT will produce a single robust measure of attention that will serve to differentiate individuals with and without ADHD, especially given the multidimensional nature of both attention as a construct and ADHD as a diagnosis. Thus, researchers and clinicians must examine the convergence of significant dependent measures on a given CPT when trying to determine the presence of attentional difficulties, a diagnostic process advocated by the CCPT manual (Conners & MHS Staff, 2002). Researchers and clinicians also must continue to examine performance on multiple measures. For example, diagnostic utility in the present study was best when combining dependent measures from both the flicker task and CCPT.

Examination of correlations (as well as the lack thereof) among CAARS scores and flicker task and CCPT dependent measures provides further understanding of these two tasks of attention in relation to ADHD symptomatology. Flicker task commission errors were significantly correlated with CAARS scores of ADHD symptomatology (both inattention and hyperactivity/impulsivity). CCPT commission errors, HIT RT SE, and detectability were significantly correlated with CAARS scores of ADHD symptomatology, and Hit SE ISI Change was significantly correlated with only hyperactivity/impulsivity. The frequent correlation of flicker task and CCPT dependent measures with CAARS indices of both inattention and hyperactivity/impulsivity indicates a lack of symptom domain specificity of CPT measures. This finding corresponds well to

results from Solanto et al. (2004) and an epidemiological study of children (Epstein et al., 2003), both of which did not find predicted symptom domain specificity of CCPT measures. Solanto et al. (2004) suggested that vigilance, effortful processing, and self-inhibition may be part of a larger self-modulatory system that influences symptom presentation, regardless of specific symptoms cluster. In contrast, Epstein et al. (1998) found no significant correlations between CCPT measures and ADHD symptomatology, citing this result as common to both child and adult CPT literature. Epstein et al. (1998) suggested that the lack of correlation may suggest that CPT performance may not directly correspond to behavioral manifestations of similar constructs, an interpretation disputed by the current findings. There were no interpretatively useful significant correlations between parallel performance measures of the flicker task and CCPT. The lack of significant correlations suggests the dissimilarity of measured constructs. As noted above, both tasks are posited to tap attentional processes, but employ different task demands that likely tap different aspects of attention and other cognitive processes.

There are several limitations of the study. First, inclusionary criteria for individuals in the ADHD group may have increased variability within the sample. The ADHD group was defined as adults who self-reported a current ADHD diagnosis and significant levels of current ADHD symptoms (based on CAARS scores). However, the present study did not include other aspects reflecting a more comprehensive diagnostic process: a structured diagnostic interview used to recognize developmental differences in adult ADHD symptom expression and to provide a differential diagnosis; and multi-informant interviews (usually of a parent) to corroborate the presence of symptoms and to obtain a retrospective childhood diagnosis (Barkley, 1998; McGough & Barkley, 2004).

Also, all three DSM-IV ADHD subtypes were combined to form the ADHD group. Thus, the ADHD sample in this study may have been more heterogeneous than a rigorously defined ADHD sample using strict diagnostic criteria.

Second, the ADHD and control group were not matched on variables that may have affected performance on CPTs (e.g., IQ, psychopathology; see Epstein et al, 1998). However, the similar educational level and screening procedure (i.e., exclusion of individuals reporting current use of long-term psychoactive medications) may have informally and partially controlled for IQ and psychopathology, respectively.

Third, the current study can generalize only to a primarily college sample. Further, the study can generalize to a predominantly female sample, such that the female overrepresentation (approximately 2:1) in the present study contrasts starkly the male overrepresentation (approximately 3:1) found in the community. In the child literature, caution has been urged when generalizing to girls with ADHD results from studies that include very small samples of girls with ADHD (Barkley, 1998). Similarly, caution should be taken in interpreting and generalizing the present results to males with ADHD given the reversal of the typical male overrepresentation.

In summary, adults with ADHD appear to exhibit variable levels of attention and hyperactivity/impulsivity deficits compared to controls, as measured by the flicker task and CCPT. However, the generally weak sensitivity and specificity of both tasks render them less than ideal measures for making diagnostic decisions. The poor diagnostic utility of these two tasks highlights the need for future research to understand more fully the attentional difficulties and performance challenges associated with ADHD. Concerning the flicker task, future studies may remove the time limit for detecting

change and add more stimuli, thereby elongating the flicker task, which may more rigorously tax the attentional abilities of individuals with ADHD. Future flicker task studies also may include additional marginal interest stimuli, which may provide a better understanding of focused attention. Rensink et al. (1997) provided valid and invalid cues during flicker conditions, which enhanced and decreased facility of detection, respectively. Future flicker task studies may examine how differential cues influence performance of individuals with and without ADHD. Longitudinal studies for both the flicker task and CCPT are needed to examine the developmental course of CPT performance. In addition, future research should examine using the flicker task and CCPT to detect treatment outcome for individuals with ADHD, such as medication response.

The present study replicates and extends findings from Rensink et al.'s (1997) seminal work, providing further support for using the flicker task to demonstrate the robust nature of change blindness. Furthermore, the flicker task provided similarly insufficient diagnostic utility for differentiating adults with and without ADHD compared to the widely used CCPT. This finding adds support to the growing evidence that CPTs—ranging from relatively unknown and untested versions such as the flicker task to well known and commercially available variants such as the CCPT—currently provide minimal utility for making diagnostic decisions regarding disorders of attention. If CPTs are to be used as diagnostic tools, future research must continue to manipulate and compare computerized measures of attention in order to create a CPT that taps a specific cognitive mechanism (of attention, response inhibition, etc.) as well as differentiates individuals based on that mechanism.

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APPENDICES

APPENDIX A

Demographic questionnaire.

Participant Contact Information/Demographics Questionnaire

Notice: This information will remain strictly confidential and will be destroyed at the completion of the study.

Name: _____

Phone: _____

Email: _____

I prefer to be contacted by _____ Phone _____ Email

Course: _____

Instructor: _____

GTA: _____

Note: This information will be used to ensure that we are able to inform your course instructor of your extra credit eligibility.

Participant Contact Information/Demographics Questionnaire

Notice: This information will remain strictly confidential and will be destroyed at the completion of the study.

Age:

_____

Sex: (circle one)

1=Male 2=Female

Race: (circle one)

1= Caucasian
2=African-American
3=Hispanic
4=Asian
5=Native American
6=Mixed (specify) _____
7=Other (specify) _____

Have you ever received an ADHD diagnosis from a physician or psychologist? (circle one)

1=Yes 2=No

Are you currently diagnosed with ADHD by a physician or psychologist? (circle one)

1=Yes 2=No

Have you ever been prescribed, or are you currently taking, medication for ADHD? (circle one)

1=Yes 2=No

If yes, which type of ADHD medication do you currently take:
(circle all that apply)

1=Ritalin
2=Metadate
3=Methylin
4=Focalin
5=Generic Methylphenidate
6=Ritalin SR
7=Ritalin LA
8=Metadate ER
9=Metadate CD
10=Methylin ER
11=Concerta
12=Adderall
13=Mixed Amphetamine Salts
14=Dexedrine
15=Dextrostat
16=Dexedrine Spansules
17=Dextroamphetamine Sulfate
18=Adderall XR
19=Strattera
20=Cylert
21=Other (specify) _____

Participant Contact Information/Demographics Questionnaire

Notice: This information will remain strictly confidential and will be destroyed at the completion of the study.

Have you ever been prescribed medication for a psychological problem (antidepressant, antianxiety, antipsychotic)? If unsure, just list any medication that has been prescribed to you for a psychological problem.
(circle one)

1=Yes 2=No

If yes, write the name of the medication(s) you have been prescribed:

_____ _____ _____

Do you *currently* take medication for a psychological problem (antidepressant, antianxiety, antipsychotic)? If unsure, just list any medication that you currently take for a psychological problem.
(circle one)

1=Yes 2=No

If yes, write the name of the medication(s) you have been prescribed:

_____ _____ _____

Do you have normal vision? (circle one)

1=Yes 2=No

If you do *not* have normal vision, do you wear glasses or contacts? (circle one)

1=Yes 2=No

How did you hear about this study? (circle one)

1=Psychology bulletin board

2=Psychology class

3=AU Psychological Services Center

4=AU Program for Students with Disabilities

5=Office of a local health care provider (specify) _____

6=Other (specify) _____

APPENDIX B

Flicker task instructions, for both practice and test blocks.

Practice block instruction screen A.

You will see a series of pictures.
Each picture will flash onscreen.

A change may occur to the picture.
For example, an object or region in the picture
may change color, change location, or appear/disappear.
There will be only one change per picture.

Your task is to determine when the picture changes.
As soon as you see the change, press the SPACEBAR.

You will then report the change to the researcher.
.
.
.
In your own words,
please retell the instructions back to the researcher.
.
.
.
Press the SPACEBAR to continue.

Practice block instruction screen B.

If you have any questions,
please ask the researcher now.
.
.
.
When you are ready
to begin the practice session,
press the SPACEBAR to continue.

Test block instruction screen A.

You completed the practice session.
.
.
.
If you have any questions,
please ask the researcher now.
.
.
.
Press the SPACEBAR to continue.

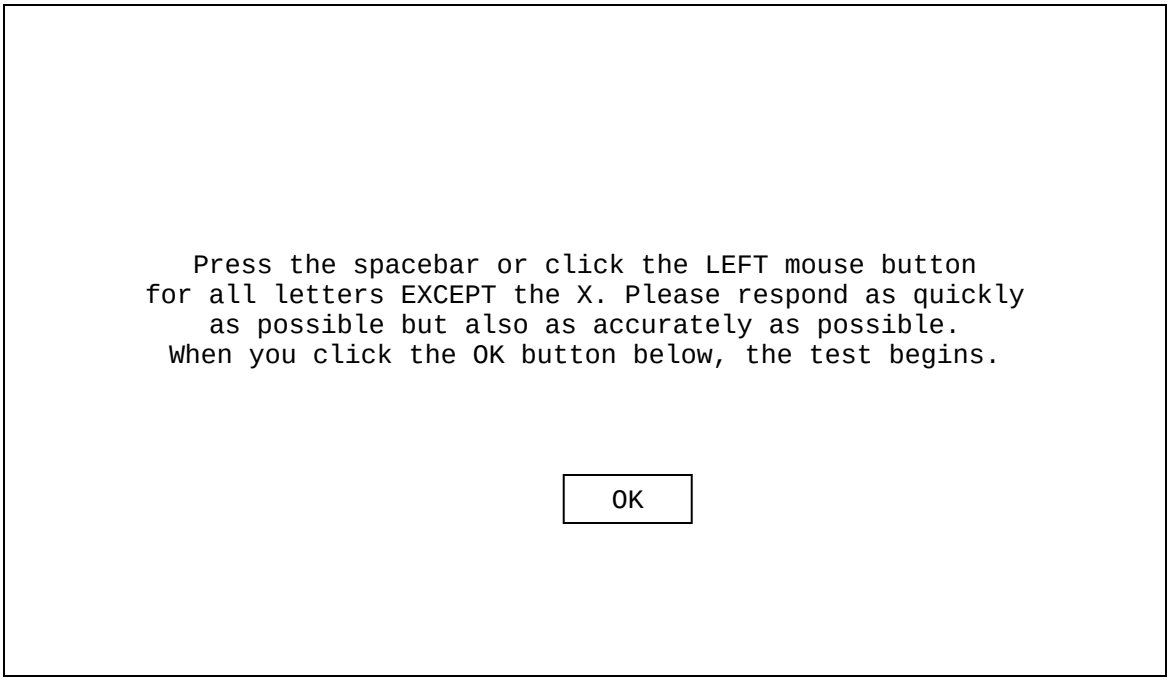
Test block instruction screen B.

Remember,
as soon as you see the change, first press the SPACEBAR
and then report the change to the researcher.
.
.
.
When you are ready
to begin the test session,
press the SPACEBAR to continue.

APPENDIX C

CCPT instructions, for both practice and test blocks.

Practice and test block instruction screen.



After the practice block instructions, the administrator stated to the participant, “Ignore the instructions regarding the left mouse button and use only the spacebar. Now please tell the instructions back to me in your own words.” After the practice block, the administrator asked the participant, “Do you have any questions?” The administrator clarified task demands as needed.