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Exploring the Performance Differences on the Flicker Task and the Conners' Continuous Performance Test in Adults With ADHD

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Objective: To examine the ability of the flicker task to demonstrate greater utility in discriminating performance in young adults with and without ADHD compared to the Conners' CPT (CCPT). **Method:** Flicker task and CCPT performance were compared between an ADHD (n = 28) and control (n = 30) group of college students. **Results:** This study replicated previous flicker task findings, providing support for using the flicker task to demonstrate the robust nature of change blindness. However, the flicker task did not demonstrate better discriminative utility than the CCPT. Task-dependent measures correlated with ADHD rating scale indices of inattention and hyperactivity/impulsivity, indicating that CPTs lack symptom domain specificity. **Conclusion:** Results support the growing evidence that CPTs currently provide only modest utility for discriminating performance in adults with and without ADHD. Recommendations are provided regarding the future study of CPTs as a valid measure of ADHD performance and the potential utility of the flicker task. *(J. of Att. Dis. 2007; 11(1) 49-63)*

Keywords: *adult ADHD; continuous performance test; change blindness; discriminative utility*

ADHD is one of the most commonly diagnosed childhood disorders. Prevalence estimates range from 3% to 7% in the current *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., rev.; *DSM-IV-TR*; American Psychiatric Association [APA], 2000) to 8% to 12% in a recent meta-analysis examining studies that used only *DSM-IV* (APA, 1994) diagnostic criteria (Faraone, Sergeant, Gillberg, & Biederman, 2003). ADHD in childhood exhibits male overrepresentation of approximately 3 to 1 and frequently persists into adulthood (Barkley, 1998). Prevalence estimates for ADHD in adulthood are 4.1% in the United States (Kessler, Chiu, Demler, & Walters, 2005) and 0.6% to 1.6% in Europe (Kooij et al., 2005). ADHD is characterized along two symptom domains, inattention-disorganization and hyperactivity-impulsivity, which yield three clinical subtypes: predominantly inattentive (ADHD-I), predominantly hyperactive-impulsive (ADHD-H), and combined (ADHD-C; APA, 2000). Individuals with ADHD have significant difficulty in the areas of attention, response inhibition, and self-regulation (Barkley, 1997). In adults diagnosed with ADHD, problems with impulsivity and inattention continue, although 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, and difficulties in friendships, marriages, and employment (Barkley, 1998).

Mental health care professionals currently debate the true nature and underlying mechanisms of ADHD and its subtypes (e.g., Barkley, 1997, 2006; Biederman & Faraone, 2005; Hinshaw & Zalecki, 2001; Span, Earleywine, & Strybel, 2002). Neuropsychological research has provided extensive support that dysregulation in the prefrontal cortex commonly (although not universally) operates in individuals with ADHD, leading to deficits in executive functioning (e.g., behavioral inhibition, sustained attention, working memory; Barkley,

Authors' Note: We extend our appreciation to Ron Rensink for granting us use of his flicker task stimuli. Address correspondence to Andrew L. Cohen, Department of Psychology, 226 Thach Hall, Auburn University, AL 36849; cohenal@auburn.edu.

2006; Biederman & Faraone, 2005). Indeed, ADHD is associated with deficits in executive neuropsychological tasks, with effect sizes (*d*) averaging .59 compared to control groups (Frazier, Demaree, & Youngstrom, 2004). Researchers have offered various theories of what constitutes the primary dysregulation in the prefrontal cortex, including deficits in brain systems mediating inhibitory control, reward and response cost, and arousal, activation, and effortful control (Biederman & Faraone, 2005). Regardless of the various mechanisms proposed to underlie ADHD and its subtypes—and given that current research largely rejects inattention as such an underlying mechanism—the fact remains that the behavioral presentations of all three ADHD subtypes share the consequence of inattention (Barkley, 2006). That is, individuals with ADHD display difficulties with attention relative to same-age and gendered peers (Barkley, 2006).

The Continuous Performance Test (CPT)

ADHD symptoms 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 have been explored as potentially diagnostically useful assessment devices (Barkley, 1998; Riccio, Reynolds, & Lowe, 2001). One of the most popular laboratory measures is the CPT. In general, CPTs require participants to maintain vigilance and react (or not) to the presence or absence of a specific stimulus within a set of continuously presented distracters.

Current research has produced equivocal results regarding the diagnostic utility of CPTs (Epstein, Conners, Sitarenios, & Erhardt, 1998; Hervey, Epstein, & Curry, 2004; Nichols & Waschbusch, 2004; 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 because of the existence of multiple CPT paradigms and varying research methodologies (Riccio et al., 2001). Literature examining CPT performance in children has been extensive, although there is a dearth of research concerning CPT performance in adults (Epstein et al., 1998; Solanto et al., 2004). Overall, CPTs exhibit moderate strength in detecting the absence of attentional and impulsive difficulties but weakness in identifying and differentiating among disorders associated with such difficulties (Barkley, 2006; Epstein et al., 1998; Riccio et al., 2001; Solanto et al., 2004).

One of the most popular commercial CPTs for diagnosing ADHD in children and adults is the Conners' CPT II (CCPT; Conners & Multi-Health Systems [MHS] Staff, 2002; Riccio et al., 2001). The CCPT is a computerized visual task that requires the individual to press the spacebar for every letter presented except the letter "X." Adult studies of CCPT diagnostic utility report weak sensitivity and moderate specificity (e.g., Epstein et al., 1998; Solanto et al., 2004). 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 (Barkley, 2006; Hervey et al., 2004).

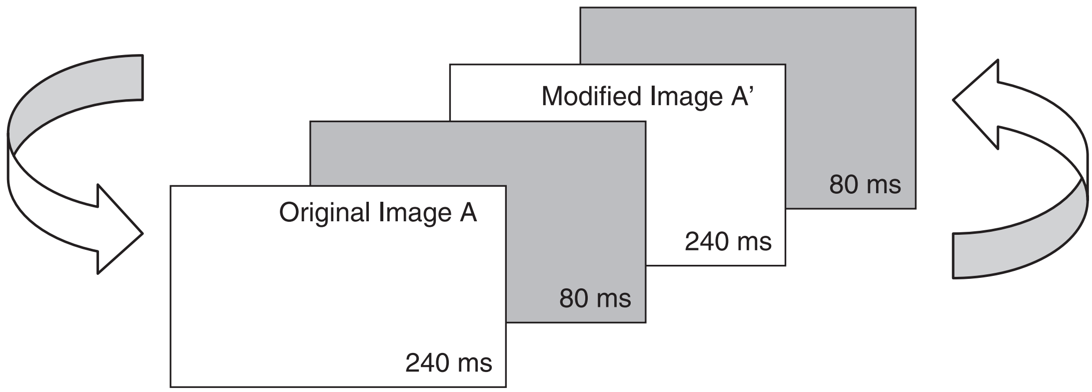
Change Blindness and the Flicker Task

Recent research on visual memory has demonstrated that people are surprisingly poor at detecting large changes in the environment from one moment to the next (e.g., Simons & Levin, 1997). Under normal viewing conditions, changes to a scene generate a motion signal—an automatic, internal cue signifying a visual change—that may be 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*.

Research has demonstrated the ecological validity of change blindness, such that change blindness has been demonstrated during a variety of increasingly naturalistic experimental paradigms: 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); saccades (Grimes, 1996); and eye blinks (O'Regan, Deubel, Clark, & Rensink, 2000).

To examine change blindness, Rensink, O'Regan, and Clark (1997) developed the flicker task (an experimental paradigm that is not commercially available). 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; also see Rensink et al., 1997). An example of an image modification is the alternating location of an object within a scene. The observer freely views the flickering display, presses a key when the change is perceived, and must then correctly describe the change. A key result of Rensink 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 detected changes to central interest than marginal interest objects. Central interest objects capture the theme of the scene (e.g., the meal enjoyed by a couple dining out), whereas marginal interest objects do not (e.g., the horizon level behind the dining couple). The argument follows that the salience or thematic centrality of central interest objects makes them more

Figure 1
The Flicker Task: An Original Image A Repeatedly Alternates With a Modified Image A', With a Blank Field Placed Between Successive Images



"interesting" than marginal interest objects. 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).

Change blindness researchers have concluded that *focused attention* is necessary for change detection (e.g., Mitroff & Simons, 2002; O'Regan et al., 2000; 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). 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 flicker task is an intentional change detection task in that observers know that changes will occur and actively search the display to find them. It is surprising 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.

Focus of the Current Study

Building on 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). 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. Given that individuals with ADHD exhibit attentional difficulties compared to peers (Barkley, 2006), ADHD, as a disorder associated with attentional difficulties, is suitable for investigation with an attention-oriented measure, the flicker task.

The current study examined the ability of the flicker task to demonstrate greater utility in discriminating performance in individuals with and without ADHD compared to 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 (such that one cycle represents a single alternation of images: Original Image A, blank screen, Modified Image A', blank screen; see Figure 1), 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, with the ADHD group expected to produce a greater number of cycles, greater variability of cycles, and lower accuracy compared to the control group. A within-subjects main effect was also predicted, with the expectation to replicate previous findings that observers more rapidly detect central than marginal interest changes (i.e., Rensink et al., 1997). For the CCPT, diagnostic group differences were predicted. Consistent with previous research (Epstein et al., 1998; Murphy, Barkley, & Bush, 2001; Walker, Shores, Trollor, Lee, & Sachdev, 2000), adults with ADHD were expected to generate more omission and commission errors and greater variability of reaction time compared to normal controls. Also, flicker task performance was hypothesized to generate better clinical sensitivity and specificity than CCPT performance.

The relationship of dependent measures among the flicker task, CCPT, and ADHD self-report rating scales were also examined. Rating 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. 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 and without ADHD do not differ in reaction time (Epstein et al., 1998; Epstein et al., 2003; Murphy et al., 2001; Roy-Byrne et al., 1997; Solanto et al., 2004; Walker et al., 2000). 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 prior research examining these assumed relationships, elevated ratings of attention problems and hyperactivity/impulsivity were expected to correlate with increased omission and commission errors, respectively.

Method

Participants

Participants were recruited through psychology classes at a large public university in East Alabama, the university's disabilities office and medical clinic, and the offices of local physicians and psychologists. An age range criteria of 19 to 25 was established to minimize heterogeneity. The university's institutional review board approved the study.

Individuals were screened for inclusion in the ADHD and control group by using a demographic questionnaire and the Conners' Adult ADHD Rating Scale–Self-Report, Long Form (CAARS; Conners, Erhardt, & Sparrow, 1999). 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. 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. These individuals 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. The three ADHD subtypes were combined to form a single group to ensure adequate statistical power for analyses (see Cohen, 1991). 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 differed significantly by diagnostic group for all scales (all ps < .001) such that individuals with ADHD reported greater ADHD symptoms and related difficulties (see Table 1).

Measures

CAARS. The CAARS assesses core symptoms of ADHD and related problems in adults 18 years of age

Table 1
CAARS T-Scores

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

Note: CAARS = Conners' Adult ADHD Rating Scales; *DSM-IV* = *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.); hyp-imp = hyperactive/impulsive.

and older. Studies have reported satisfactory test-retest reliability (coefficients for scales in the 18- to 29-year-old normative sample ranged from .64 to .89), internal consistency (Cronbach's alpha coefficients for a preliminary version of the scales ranged from .88 to .91), criterion-related validity, concurrent validity, and discriminative validity of the questionnaire (Conners et al., 1999).

Flicker task. E-Prime software was used to present stimuli on a PC desktop computer (17 in, 43.18 cm monitor, 1,024 × 768 resolution, 75 Hz refresh rate). Flicker sequences included an Original Image A, a Modified Image A', and a gray blank field. Images 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 × 17.6 cm) of real-world scenes used by Rensink et al. (1997). Six item-pairs composed the trial set, and 42 item-pairs composed 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. (1997) 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 excessive 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 × 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. Thus, 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 vs. control group) served as a between-group independent measure.

Within-subjects. For the flicker task, degree of interest (central and marginal) and change type (presence/absence, color, and 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), and 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 normed measures based on the performance of 1,920 nonclinical standardization sample participants, of which 237 were between the ages of 18 and 34 (Conners & MHS Staff, 2002). The CCPT yields T-scores for omission and commission errors, signal detection parameters, and reaction time. The average speed of all target responses for the entire test (Hit Reaction Time) serves as an overall response time measure. Variability dependent measures include the standard error of Hit Reaction Time (Hit Reaction Time SE); a measure of "within-respondent" variability, which compared the variability of 18 time blocks to the overall variability, Hit Reaction Time SE (Variability); the change in reaction time across the duration of the test (Hit Reaction Time 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 Reaction Time 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 include the failure to respond to target (non-X) letters (Omission Error), the response to nontarget (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 nontargets (Response Style, B). High T-scores (i.e., ≥ 60) indicate poor performance for all measures. However, high and low scores for B and Hit reaction time can be noteworthy. The CCPT also generates a Confidence Index score (based on a discriminative function analysis) that provides an overall indication of whether the profile obtained for a respondent best fits a clinical or nonclinical profile ($n = 48$ individuals with ADHD between the ages of 18 and 34 in the standardization sample). Confidence Index values less than 40 or higher than 60 are purported to offer evidence for nonclinical or clinical classification, respectively (Conners & MHS Staff, 2002). Split-half reliability for the CCPT measures ranges from .73 to .95. Test-retest reliabilities for a 3-month interval range from .55 to .84.

Procedure

Prior to participation in the test session, individuals completed a screening packet containing an informed consent form, a demographic questionnaire, and the CAARS. Individuals meeting study criteria were contacted to schedule a test session.

The flicker task and CCPT were administered in counterbalanced order during a 1 hr test session. Participants sat comfortably without head restraint approximately 50 cm from the monitor. Testing took place in a well-lit room free of distraction; white noise was used to attenuate external sound. The principal investigator remained in the room during testing because of flicker task requirements and, thus, for experimental control. Participants with ADHD currently taking medication for ADHD consented to abstain from ingesting those medications on the day of their computer test session and verbally confirmed adherence to this procedure at the time of testing.

For the flicker task, participants read on-screen instructions 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. For the CCPT, participants read on-screen instructions to press the spacebar for every letter presented except the letter "X." Prior to each test administration, participants paraphrased the instructions (to ensure understanding of the task) and completed the respective practice administrations.

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.

Results

Between-Group and Within-Subjects Differences

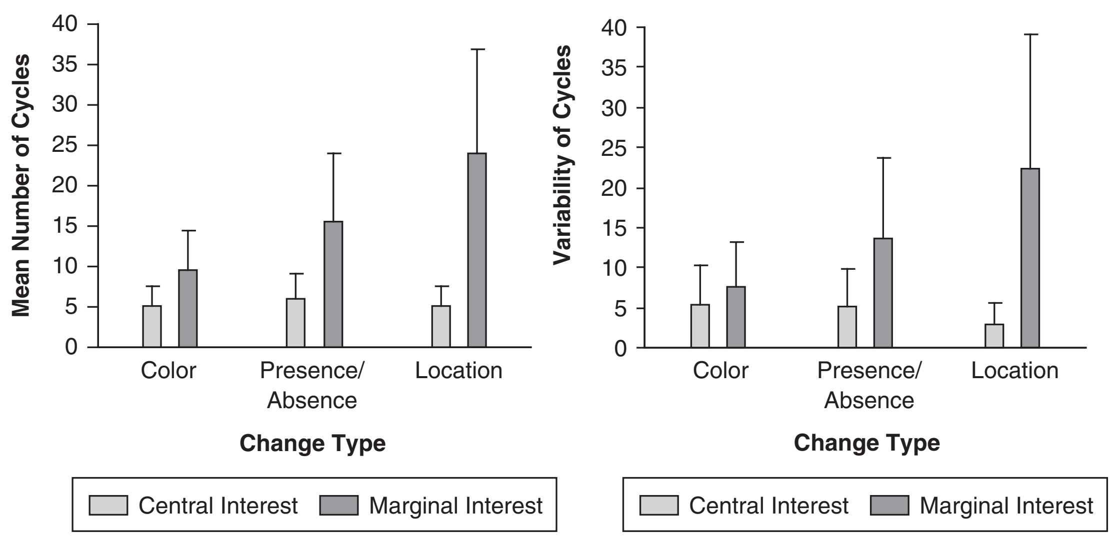
Flicker task. Prior to conducting primary analyses, the mean number of cycles needed to detect change was calculated for each flicker task item-pair, and outlier responses were recoded as the number of cycles immediately below 3 standard deviations above the mean of the respective item-pair. Outlier 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) × 2 (Degree of Interest) × 3 (Change

Table 2
Group Performance on Flicker Task Measures

Measure	ADHD Group (*n* = 28)		Control Group (*n* = 30)		Groups Combined (*n* = 58)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Mean number of cycles						
Degree of interest						
Central	5.86	2.18	4.93	1.86	5.38	2.06
Marginal	15.48	8.03	16.58	5.91	16.05	6.97
Change type						
Color	7.27	3.47	7.21	2.45	7.24	2.96
Presence/absence	10.38	5.92	10.84	4.77	10.62	5.31
Location	13.64	7.32	13.86	5.59	13.75	6.42
Variability of mean number of cycles						
Degree of interest						
Central	6.05	3.50	4.58	3.23	5.29	3.41
Marginal	16.18	8.52	18.45	9.69	17.35	9.14
Change type						
Color	7.14	4.46	7.86	4.94	7.51	4.69
Presence/absence	9.82	7.91	13.25	8.40	11.60	8.27
Location	17.21	9.79	18.30	11.24	17.77	10.49

Figure 2
Flicker Task Mean Number of Cycles and Variability of Mean Number of Cycles Needed to Detect Change Plotted by Change Type and Degree Of Interest



Type) mixed-design ANOVA was conducted for mean number of cycles. There was a significant main effect of degree of interest, $F(1, 56) = 185.80$, $p < .001$, $\eta_{p^2} = .77$, such that participants more rapidly detected central than marginal changes. There was also a significant main effect of change type, $F(2, 112) = 50.31$, $p < .001$, $\eta_{p^2} = .47$. Bonferroni pairwise comparisons revealed that mean number of cycles differed for each change type (all *p*s < .001), with cycles increasing in the following order of change type: color, presence/absence, and location. However, there was a significant interaction between degree of interest and change type, $F(2, 114) = 64.13$, $p < .001$, $\eta_{p^2} = .53$ (see Figure 2). Bonferroni pairwise comparisons revealed no difference of detecting central interest changes across the three change types of presence/absence, color, and location (all *p*s > .05; $M = 6.04$, *SD* = 3.00; *M* = 5.05, *SD* = 2.25; *M* = 5.06, *SD* = 3.03, respectively). In contrast, a significant difference of detecting marginal interest changes across change type was found (all *p*s < .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, *SD* = 5.02; *M* = 15.63, *SD* = 9.15; *M* = 24.00, *SD* = 11.81, respectively).

Also with respect to flicker task performance (see Table 2), a 2 (Diagnostic Group) × 2 (Degree of Interest) × 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, $F(1, 56) = 96.28$, $p < .001$, $\eta_{p^2} = .63$, such that participants exhibited greater variability for marginal than central changes. There was also a significant main effect of change type, $F(2, 112) = 20.16$, $p < .001$, $\eta_{p^2} = .27$. Bonferroni pairwise comparisons revealed that variability of cycles differed for each change type (all *p*s < .015), with variability increasing in the following order of change type: color, presence/absence, and location. However, there was a significant interaction between degree of interest and change type, $F(2, 114) = 46.97$, $p < .001$, $\eta_{p^2} = .46$ (see Figure 2). Bonferroni pairwise comparisons revealed a significant difference of detecting central interest changes across change type such that only the variability of cycles for the change type of location (*M* = 2.94, *SD* = 2.56) was less than that of presence/absence (*p* = .026; *M* = 5.14, *SD* = 4.97) and color (*p* = .021; *M* = 5.32, *SD* = 4.81). In contrast, a significant difference of detecting marginal interest changes across change type was found (all *p*s < .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, *SD* = 5.99; *M* = 13.57, *SD* = 11.13; *M* = 22.42, *SD* = 14.08, respectively).

To examine flicker task performance throughout time, a 2 (Diagnostic Group) × 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.

To examine accuracy, independent samples *t* tests were conducted separately for commission and omission errors. Participants with ADHD committed more commission errors than did controls (*M* = 3.00, *SD* = 2.16; *M* = 1.23, *SD* = 1.72, respectively), $t(1, 56) = 3.46$, $p = .001$, $\eta_{p^2} = .18$. No difference in omission errors was found (ADHD: *M* = 0.32, *SD* = 0.82; controls: *M* = 0.30, *SD* = 0.47).

To examine accuracy throughout time, 2 (Diagnostic Group) × 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, $F(5, 280) = 3.08$, $p = .010$, $\eta_{p^2} = .05$, and omission errors, $F(5, 280) = 2.92$, $p = .046$, $\eta_{p^2} = .04$, 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 varied with time. That is, 2 (Diagnostic Group) × 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, $F(1, 56) = 8.54$, $p = .005$, $\eta_{p^2} = .13$, and omission errors, $F(1, 56) = 7.25$, $p = .009$, $\eta_{p^2} = .12$. Participants made a greater number of commission and omission errors in the first half compared to the second half of the flicker task.

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, $F(13, 44) = 2.05$, $p = .039$, $\eta_{p^2} = .38$. The mean raw (Confidence Index only) and T-scores for all dependent measures were in the nonclinical range (see Table 3). Participants with ADHD made more commission errors than did controls. Participants with ADHD had higher d' T-scores than did control participants, suggesting a less sensitive threshold to stimulus events than for control participants. Participants with ADHD had greater variability of mean reaction time overall as well as for the different ISIs compared to controls.

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 self-reported inattention, hyperactivity/impulsivity, or total ADHD symptoms (see Table 4). Several flicker task and CCPT dependent measures were correlated with CAARS indices of inattention, hyperactivity/impulsivity, and total ADHD symptoms, indicating that dependent measures showing significant between-group differences were associated with 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.

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 was significant (all *p*s > .05), except for the significant relationship between the accuracy measures of

Table 3
Group Performance on CCPT Measures

Measure	ADHD Group (n = 28) M	SD	Control Group (n = 30) M	SD	$F_{1, 56}$	p	η_{p^2}
Reaction time							
Hit RT	44.61	9.41	41.75	8.6	1.45	.234	.03
Variability							
Hit RT SE	50.94	11.06	43.69	8.60	7.82	.007	.12
Variability	50.60	8.82	46.18	8.35	3.84	.055	.06
Hit RT block change	46.39	14.28	47.99	6.72	0.30	.583	.01
Hit SE block change	52.26	10.57	52.29	8.93	0.00	.991	.00
Hit RT ISI change	55.00	12.06	49.50	7.11	4.55	.037	.08
Hit SE ISI change	52.95	10.84	49.63	7.72	1.83	.181	.03
Perseverations	51.92	12.51	48.88	5.62	1.46	.232	.03
Accuracy							
Omission errors	48.43	6.40	48.77	14.41	0.01	.910	.00
Commission errors	56.58	10.75	48.67	8.89	9.39	.003	.14
Detectability (d’)	56.11	8.52	48.63	8.94	10.60	.002	.16
Response style (B)	46.22	2.41	47.24	4.69	1.06	.308	.02
Overall profile (clinical vs. nonclinical)							
Confidence index	40.62	20.89	31.41	18.90	3.11	.083	.05

Note: CCPT = Conners’ Continuous Performance Test; RT = reaction time; SE = standard error; ISI = interstimulus interval. All scores except Confidence Index (raw) refer to T-scores.

flicker task mean number of cycles needed to detect change for Time Block 4 and CCPT d’, r = .270, p = .040.

Clinical Sensitivity and Specificity

Flicker task. To examine the ability of the flicker task to discriminate performance in 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 .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 discriminative utility of the CCPT, dependent measures that demonstrated statistically significant between-group differences (d’, Commissions Errors, Hit Reaction Time SE, and Hit Reaction Time 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 Reaction Time SE and d’ remained in the final equation and were associated, respectively, with a beta weight of .09 and .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 discriminative 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 Reaction Time SE and d’ remained in the final equation and were associated, respectively, with a beta weight of .49, .10, and .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

Table 4
Pearson Correlations Between Task Dependent Measures and ADHD Symptomatology

	CAARS		
	Inattentive Symptoms	Hyp/imp Symptoms	ADHD Symptoms Total
CCPT dependent measure			
Reaction time			
Hit RT	.121	.077	.106
Variability			
Hit RT SE	.318*	.318*	.334*
Variability	.229	.194	.224
Hit RT block change	–.084	–.108	–.099
Hit SE block change	–.041	–.013	–.030
Hit RT ISI change	.175	.236	.213
Hit SE ISI change	.180	.283*	.238
Perseverations	.049	.152	.100
Accuracy			
Omissions errors	–.008	.077	.032
Commission errors	.356**	.349**	.371**
Detectability (d’)	–.412**	–.406**	–.430**
Response style (B)	–.179	–.020	–.113
Overall profile			
Confidence index	.069	.110	.092
Flicker task dependent measure			
Mean number of cycles needed to detect change (reaction time)			
All stimuli	.048	.064	.058
Central interest changes	.236	.214	.238
Marginal interest changes	.003	.035	.018
Presence/absence changes	.034	.071	.053
Color changes	.054	.119	.088
Location changes	.047	.010	.032
Standard deviation for the mean number of cycles needed to detect change (variability)			
All stimuli	–.041	–.029	–.038
Central interest changes	.194	.186	.200
Marginal interest changes	–.047	–.041	–.047
Presence/absence changes	–.118	–.056	–.095
Color changes	–.031	.079	.020
Location changes	.024	–.023	.003
Accuracy			
Omissions errors	.030	.017	.025
Commission errors	.350**	.461**	.421**

Note: n = 58. CAARS = Conners’ Adult ADHD Rating Scales; Hyp/imp = hyperactive/impulsive; CCPT = Conners’ Continuous Performance Test; RT = reaction time; SE = standard error; ISI = interstimulus interval; All scores refer to raw scores.
*p < .05. **p < .01.

specificity coefficient of 80%. The overall correct classification rate was 78%. Positive and negative predictive power were 78% and 77%, respectively.

Discussion

Contrary to current prediction, the flicker task does not demonstrate better discriminative utility compared to the CCPT. Instead, both measures provide generally weak ability to discriminate between individuals with and without ADHD. Current CCPT sensitivity (71%) appears to be an improvement over results from prior adult 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, because of the restricted age range, 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. 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 (Epstein et al., 1998; Solanto et al., 2004) 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 raises concerns regarding their utility in discriminating performance in adults with and without ADHD (Epstein et al., 1998; Hervey et al., 2004; Solanto et al., 2004).

It should be noted that studies (including the present research) examining the CCPT have used various methods to determine clinical sensitivity and specificity, such as using logistic regression or discriminative function analysis, examining between-group differences, or establishing an arbitrary cutoff score for a given dependent measure to ascribe abnormal performance (e.g., Epstein et al., 1998; Solanto et al., 2004; Walker et al., 2000). 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 (or discriminative utility, as in the present study) suggests exercising caution when interpreting results.

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, findings that are consistent with current prediction and 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 d' 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, although previous CCPT research has shown inconsistent results for this variable. A recent meta-analysis of neuropsychological test performance showed omission errors to yield significant group differences (Frazier et al., 2004). However, some researchers failed to find group differences for omission errors (Epstein, Johnson, Varia, & Conners, 2001; Kovner et al., 1998), and others who did find group differences reported that IQ differences (Murphy et al., 2001) and order effects (Epstein et al., 1998) accounted for this result.

With respect to flicker task performance, participants detected more quickly central compared to marginal interest changes, which replicates previous flicker task findings (Mulfinger, 2005; Rensink et al., 1997; 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, and 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. 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, although, as cited above, results have been inconsistent for omission errors yielding a group difference (Epstein et al., 1998;

Epstein et al., 2001; Frazier et al., 2004; Kovner et al., 1998; 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 with 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 differences in diagnostic group performance 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 recent study demonstrating that performance of children with ADHD on commercially available computer games and a game-like version of the CCPT was equivalent to that of typically developing children (Shaw, Grayson, & Lewis, 2005).

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 (CCPT) compared to tasks of focused attention (flicker task). 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 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, clinical sensitivity and specificity in the present study were 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. 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, the study employed a two-group design (ADHD and control group) and, thus, did not include a nonnormal, non-ADHD group. Without this third group, the study can speak to the performance differences between the ADHD and control group but cannot comment on the diagnostic utility of the flicker task and CCPT.

Second, 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.

Third, 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).

Fourth, the current study can generalize only to a primarily college sample. Furthermore, 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 these two tasks highlight 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 and CCPT provided a similarly weak ability to demonstrate performance differences and, thus, to discriminate performance in adults with and without ADHD. 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 only modest utility for discriminating performance in individuals with and without ADHD (Hervey et al., 2004; Riccio et al., 2001). If CPTs are to provide discriminative utility, future research must continue to manipulate and compare computerized measures of attention 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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