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Tara T. Lineweaver
*Butler University*, tlinewea@butler.edu

Suneeta Kercood
*Butler University*, skercood@butler.edu

Nicole B. O'Keeffe

Kathleen M. O'Brien

Eric J. Massey

***See next page for additional authors***

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**Authors**

Tara T. Lineweaver, Suneeta Kercood, Nicole B. O'Keeffe, Kathleen M. O'Brien, Eric J. Massey, Samantha J. Campbell, and Jenna M. Pierce

# The effects of distraction and a brief intervention on auditory and visual-spatial working memory in college students with attention deficit hyperactivity disorder

**Tara T. Lineweaver[1] , Suneeta Kercood[2], Nicole B. O'Keeffe[1] , Kathleen M. O'Brien[1] , Eric J. Massey[1] , Samantha J. Campbell[1] , and Jenna N. Pierce[1]**

[1]Department of Psychology, Butler University, Indianapolis, IN, USA
[2]College of Education, Butler University, Indianapolis, IN, USA

Two studies addressed how young adult college students with attention deficit hyperactivity disorder (ADHD) (*n* = 44) compare to their nonaffected peers (*n* = 42) on tests of auditory and visual–spatial working memory (WM), are vulnerable to auditory and visual distractions, and are affected by a simple intervention. Students with ADHD demonstrated worse auditory WM than did controls. A near significant trend indicated that auditory distractions interfered with the visual WM of both groups and that, whereas controls were also vulnerable to visual distractions, visual distractions improved visualWM in the ADHD group. The intervention was ineffective. Limited correlations emerged between self-reported ADHD symptoms and objective test performances; students with ADHD who perceived themselves as more symptomatic often had better WM and were less vulnerable to distractions than their ADHD peers.

Research studies in cognitive science and neuroscience have frequently demonstrated that adults and children with attention deficit hyperactivity disorder (ADHD) have significant deficits in working memory that may be associated with dysfunction in the brain's frontal lobes (Dowson et al., 2004; Swanson & Sachse-Lee, 2001). Working memory is the capacity to simultaneously store and manipulate information (Baddeley, 2003). This ability is responsible for the short-term storage and online manipulation of information necessary for higher cognitive functions (Baddeley, 1986; Shallice, 1988) and allows complex cognitive processes to occur on complex tasks despite distractions (Berti & Schröger, 2003; Swanson & Seigel, 2001).

Researchers have examined two primary types of working memory, auditory and visual-spatial, in young adult patients with ADHD. Visual-spatial working memory has received relatively more attention in the literature. Several studies have documented visual-spatial working memory deficits in adults with ADHD (Clark et al., 2007; Dowson et al., 2004; McLean et al., 2004; Young, Morris, Toone, & Tyson, 2007), as well as deficits in sustained visual attention (Egeland, 2007). ADHD related visual-spatial working memory deficits tend to become more pronounced with increased task difficulty (Young et al., 2007) and may be associated with dysfunction in right prefrontal cortex brain regions (Clark et al., 2007). Although some researchers believe that spatial working memory impairments are secondary to the difficulties with inhibitory control that are often associated with ADHD (Ross, Harris, Olincy, & Radant, 2000), others view the spatial working memory deficit as a primary problem (Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004).

Only a few studies to date have included both auditory and visual-spatial working memory tasks in their procedures. Barkley, Murphy, and Kwasnik (1996) found that young adults with ADHD had impaired sustained attention, auditory working memory, and visual-spatial working memory compared to a similar group of young adults without ADHD. Similarly, Karatekin and Asarnow (1998) documented deficits on both an auditory digit span test and a visual dot location working memory test in young adults with ADHD. In a more recent study, Murphy, Barkley, and Bush (2001) documented intact auditory working memory but impaired nonverbal working memory in a group of young adults with ADHD once overall intellectual abilities were statistically controlled for. Thus, some studies suggest that young adults with ADHD demonstrate deficits in both auditory and visual-spatial working memory, whereas others indicate that ADHD may impair visual-spatial, but not auditory, working memory.

Working memory is thought to be integral to filtering out distractions, and distractibility is a hallmark of ADHD. However, very few studies have directly examined how adults with ADHD respond to distractions in an experimental setting. Those that have investigated this issue have demonstrated that distractions such as external noise, movement, or parallel activities interfere with working memory tasks in all individuals, but this interference may be more pronounced for both adults and children with ADHD given their limited attentional resources (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Berti & Schröger, 2003; Corbett & Stanczak, 1999; Higginbotham & Bartling, 1993; Kercood & Grskovic, 2010; Söderlund, Sikström, & Smart, 2007). However, no research to date has examined the effects of different types of distractions (visual versus auditory) on specific types of working memory in young adults with ADHD. There is also limited research on the effects of interventions to improve working memory for individuals with ADHD.

Although psychostimulant medications have been shown to improve working memory (Turner, Blackwell, Dowson, McLean, & Sahakian, 2005), medical treatments for ADHD may cause negative side effects and can lead to prescription medication abuse (Advokat, 2010; Davis-Berman & Pestello, 2010; Janusis & Weyandt, 2010). Furthermore, improvements in working memory associated with medications are likely to depend on medication levels, disappearing when medication levels drop between doses. Nonmedical interventions may circumvent these disadvantages. Neurofeedback procedures utilizing clinical EEG have demonstrated positive effects on general attention in ADHD patients (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003), but the impact of this procedure on working memory tasks more specifically has not been assessed. In a separate line of research, Klingberg, Fossberg, and Westerberg (2002) trained patients with ADHD and healthy controls to complete four complex working memory tasks. Training sessions lasted approximately 25 min a day and took place daily across three to four weeks. Patients with ADHD and their non-affected peers demonstrated significant improvements both on trained and on novel working memory tasks. These results suggest that working memory can be improved without medications. However, the training programs implemented in this study required a large number of sessions across several weeks to exert a significant effect.

In a more recent study using a single-subject, changing-conditions design (Kercood, Grskovic, Lee, & Emmert, 2007), school-aged students with ADHD performed worse on a verbal math problem-solving task in the presence of auditory distractions, but their performance improved when they were given a Tangle Puzzle Junior (http://www.tangletoys.com/) to manipulate during the task. The Tangle Puzzle Junior, a plastic circle-shaped toy with a series of interconnected, pivotable 90◦ curves, offered students a quiet fine-motor activity with a toy that was flexible and easy to manipulate. Optimal stimulation theory posits that all individuals require an optimal amount of stimulation and arousal to maintain their attentional focus, but individuals with ADHD need more stimulation than their nonaffected peers to maintain their optimal state (see Zentall, 1983, 2005, for reviews). The researchers hypothesized that manipulating a small toy would help students with ADHD focus on the task by increasing environmental stimulation to more advantageous levels. Consistent with their hypothesis, students demonstrated fewer inappropriate motor movements, less off-task behavior, and a greater number of correct solutions to the mathematics problems when manipulating the Tangle Puzzle Junior, suggesting that a very simple nonmedical intervention may help ameliorate the effects of inattention and distractibility on the working memory of students with ADHD without requiring weeks of extensive training.

The above studies on nonmedical interventions were conducted primarily on children with ADHD. Although ADHD must first manifest in childhood to warrant diagnosis, numerous longitudinal research studies have shown that the symptoms of this disorder rmay continue into adulthood (Barkley, 1998; Shekim, Asarnow, Hess, Zaucha, & Wheeler, 1990). ADHD affects 2% and 11% of the college student population (DuPaul, Weyandt, O'Dell, & Varejao, 2009; Weyandt & DuPaul, 2008), and college students who are diagnosed with ADHD are at increased risk of being placed on academic probation, having a lower grade point average, experiencing more academic problems, and failing repeatedly than are students without this disorder (Blasé et al., 2009; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999; Norvilitis, Sun, & Zhang, 2010; Norwalk, Norvilitis, & MacLean, 2009). Despite these potential academic difficulties, young adults with ADHD are enrolling in postsecondary education in increasing numbers (Dipeolu, 2011; DuPaul et al., 2009; Weyandt & DuPaul, 2008), and all higher education institutions are mandated by federal law (Section 504 of the Rehabilitation Act, 1977) to provide services and accommodations to ensure success in the academic and career pursuits of these students. Auditory as well as visual distractions permeate college classrooms, and more knowledge about how distractions impact attention in college students with ADHD on particular types of tasks could contribute to creating classroom environments more conducive to these students' success. Additionally, an intervention, such as the introduction of the Tangle Puzzle Junior, could offer college students with ADHD an inexpensive, nonobtrusive method for improving their attention and performance in the classroom, reducing their reliance on medications.

Based on the above review of the literature, we designed two studies to address three primary research questions: (1) How do young adult college students with ADHD compare to their nonaffected peers on tests of auditory and visual-spatial working memory? (2) What effects do auditory and visual distractions have on the auditory and visualspatial working memory abilities of young adult college students with ADHD? and (3) Can a simple intervention improve attention in young adult college students with ADHD? The two studies were conducted concurrently with the same group of participants. Both studies received approval from the Butler University Institutional Review Board prior to data collection.

## EXPERIMENT 1

The first study addressed the first two of our three primary research questions. We hypothesized that college students with ADHD would be more impaired on tests of both auditory and visualspatial working memory relative to students their age without ADHD and that both auditory and visual distractions would interfere more with working memory in college students with ADHD than in those without the disorder regardless of the type of working memory task (auditory or visual-spatial).

## Method

### Participants

Participant recruitment spanned several college campuses. We placed advertisements in campus newspapers and requested that student disability offices send out emails informing their students of the study. Fliers in doctors' offices and at local college student gathering places also informed potential participants about the research project. A total of 44 college students who had an existing diagnosis of ADHD volunteered to participate. Students with ADHD provided written documentation of their diagnosis based on recent clinical evaluations to ensure a current formal diagnosis of the disorder. Those who reported only a past history of ADHD symptomatology without a current diagnosis were excluded from the study. Documentation included a copy of a current prescription for a medication used to treat ADHD and a note from a physician or a report from a psychologist verifying the current diagnosis or verification from the office of Student Disabilities that the student was registered with them and carried a current diagnosis of ADHD. Of the students in the ADHD group, 24 (55%) reported receiving academic accommodations in their collegiate courses at the time of their participation, and 21 of them (48%) utilized the Student Disabilities Office as a means of documenting their diagnosis. Although students were not directly queried about their medication regimen, the Student Disabilities Office verified that 17 of these 21 students (39% of the ADHD group) had a prescription and reported taking medication at the time that they registered their disability; one had been referred for a medical consultation to determine the appropriateness of psychostimulant treatment, and three reported that they were not currently utilizing stimulant medications. An additional 20 of the 44 students (45%) in the ADHD group used a current prescription as proof of their diagnosis. Thus, the majority of the ADHD participants (at least 84%) probably had access to psychostimulant medications at the time of the study; we did not ask participants to alter their regular medication schedule at the time of their participation.

Forty-two college students with neither ADHD nor LD currently or in the past served as age and education-matched controls. All participants were enrolled in a four-year college program or in a graduate program at the time of their participation. For participant demographics including age, gender, race, and self-reported ADHD symptomatology (see Table 1).

### Materials

*Internal Restless Scale (IRS)*. The IRS (Weyandt et al., 2003) assesses the construct of "mental restlessness" frequently reported by adults with ADHD. A self-report measure, the IRS presents 24 statements such as "Thoughts race through my mind," "I feel internally restless," and "While listening to others my attention drifts to unrelated thoughts." Participants rate each item on a 7-point Likert scale, ranging from 1 = "none of the time" to 7 = "all of the time." A study by Weyandt et al. (2003) evaluated the reliability and validity of the IRS. The IRS correlates significantly with other rating scales, such as the Adult Rating Scale and demonstrates adequate test–retest reliability ($r = .89$). More importantly, the IRS successfully differentiates college students with ADHD from their nonaffected peers ($\eta 2 = .431$; Weyandt et al., 2003).

*Conners' Adult ADHD Rating Scale (CAARS).* The CAARS is a reliable and valid self-report measure of ADHD symptoms for use with adults. It requires participants to respond to 66 items by rating themselves on behaviors and characteristics commonly associated with ADHD (Conners, Ehrhard, & Sparrow, 1999).

*Digit Span (DS).* The DS subtest from the Wechsler Memory Scale-Third Edition (Wechsler, 1997) involves presenting participants with increasingly longer sequences of single-digit numbers. For the first portion of this test, participants repeat the sequence aloud in order of presentation (forward span) to measure auditory attention capacity. For the second portion, they recite the sequence in reverse order (backward span) to assess auditory working memory.

*Paced Auditory Serial Addition Test (PASAT).* During the PASAT (Gronwall & Sampson, 1974), participants hear a sequence of single-digit numbers. They add adjacent digits together and verbally report the sum. While calculating the sum, they must also remember the last digit they heard in order to add it to the next number presented. The digits occur 3 s apart during the first trial (PASAT 3.0) and 2.0 s apart during the second trial (PASAT 2.0).

*Spatial Span (SS).* A visual analog of the DS test, the SS subtest, also from theWechsler Memory Scale-Third Edition (Wechsler, 1997), requires participants to watch the examiner tap increasingly longer sequences of raised, blue blocks positioned arbitrarily on a white board. Participants tap the blocks in the same order they witnessed (forward span) or in the reverse order (backward span).

*N-Back.* During the N-Back (Awh et al., 1996, Cohen et al., 1994, 1997; Smith & Jonides, 1997), participants view a series of letters that appear serially on a computer screen. Their task is to inform the examiner whenever a letter is identical to the letter that came immediately before it (1-Back). In subsequent trials, the task becomes more difficult as the participant attempts to inform the examiner when the letter matches the one that came two before it (2-Back) or three before it (3-Back).

## Procedure

Participants participated in two individual testing sessions two weeks apart. To encourage participation and prevent attrition, they received $30 in compensation after they had completed both testing sessions.

The first testing session involved the two questionnaires evaluating symptoms of ADHD (the IRS and the CAARS) and four tests of working memory: two auditory (DS and the PASAT), and two visual-spatial (SS and the N-back). During the second testing session, random assignment determined which of three conditions each participant experienced: (1) no distraction (n = 30), (2) visual distraction (n = 29), or (3) auditory distraction (n = 27). Participants completed the same battery of four working memory tests, either in the absence (no distraction condition) or presence (visual and auditory distraction conditions) of distractions. Those in the visual distraction condition took the tests while sitting approximately 18 in to the left of an open laptop computer that displayed random photos of college students at a rate of one every 4 s. Those in the auditory distraction condition completed the working memory tests while a tape recorder that was concealed at the opposite end of the room played a recorded conversation between several college students, simulating two students conversing just outside the testing room.

The six Diagnosis × Distraction groups that resulted from this research design were matched in age and gender, but, as expected, participants with ADHD scored significantly higher than those without ADHD on both the IRS, $F(1, 74) = 90.13$, $p < .001$, and the CAARS ADHD Index, $F(1, 76) = 76.35$, $p < .001$. The significant difference between the ADHD group and control group in ADHD symptoms was consistent across the three distraction conditions (Diagnosis × Distraction: both $F\text{s} < 1$). (For details, see Table 2.)

## Results

### Group differences in auditory and visual-spatial working memory at baseline

A 2 (Group: ADHD versus control) × 2 (Test Difficulty: easy versus hard) mixed model analysis of variance (ANOVA) tested the first hypothesis. Scores on each of the four primary working memory tests from the first testing session served as the dependent variables in this series of analyses. (See Table 3.) For the DS and SS tests, forward span comprised the easy condition and backward span the hard condition. For the PASAT, the slower 3-s rate of presentation was the easy condition, and the faster 2.0-s presentation rate, the more difficult. For the N-Back, three levels of difficulty were included with 1-Back being the easiest, 2-Back intermediate, and 3-Back the hardest.

Only data from the DS test supported the hypothesis that young adult college students with ADHD would demonstrate more difficulty with working memory than those college students without ADHD. For DS, participants generally performed better when repeating digits forward than when repeating digits backward, test difficulty main effect, $F(1, 84) = 210.41$, $p < .001$, $\eta p^2 = .72$. More importantly, this effect was more pronounced for students with ADHD than for controls, Group × Test Difficulty interaction, $F(1, 84) = 4.14$, $p < .05$, $\eta p^2 = .05$. (See Figure 1.) Thus, college students with ADHD were less efficient than those without ADHD in their auditory working memory, but they did not differ from controls in their simple auditory attention capacity.

For the other three working memory tests, participants also generally performed better on the easy than on the more difficult test items: test difficulty main effect for PASAT, $F(1, 84) = 150.49$, $p < .001$, $\eta p^2 = .64$; for SS, $F(1, 84) = 10.58$, $p < .01$, $\eta p^2 = .11$; and for N-Back, $F(2, 83) = 44.53$, $p < .001$, $\eta p^2 = .52$. (See Table 3.) However, the magnitude of this effect did not depend on whether participants were in the ADHD group or in the control group, all Group × Test Difficulty $F\text{s} < 1$, all $\eta p\ 2 < .012$. Similarly, the main effect associated with ADHD group did not reach significance in any of the analyses, all group $F\text{s} < 3$, ns, all $\eta p^2 < .031$.

### Effect of visual and auditory distractions on working memory

A series of 2 (Group: ADHD versus control) × 3 (Distraction Condition: none versus visual versus auditory) × 2 (Time: baseline versus retest) mixed model ANOVAs examined whether distractions interfered more with the working memory of young adult college students with

ADHD than their nonaffected peers. To ease interpretability, we analyzed data from the easy and the hard condition of each working memory test separately. In addition, we only examined three effects in each analysis: (1) the Group × Time interaction (differences in practice effects for college students with and without ADHD), (2) the Distraction × Time interaction (the differential effect of the three distraction conditions on baseline-to-retest changes in performance across both groups), and (3) the Group × Distraction × Time interaction (whether the impact of the three distraction conditions on baseline-toretest changes in performance depends on whether participants are diagnosed with ADHD).

For forward DS, control participants performed better at retest than at baseline, whereas participants with ADHD did not show this practice effect: Group × Time, *F*(1, 80) = 7.42, *p* < .01, $\eta p^2$ = .09. (See Table 4.) Distractions did not have a differential effect on changes in DS scores from baseline to retest, Distraction × Time, *F*(2, 80) = 1.74, *p* = .18, $\eta p^2$ = .04, nor did the distractions differentially affect the performances of participants in the ADHD versus control groups, Group × Distraction × Time, *F*(2, 80) = 1.37, *p* = .26, $\eta p^2$ = .03. A similar pattern of results emerged for backward DS, although the Group × Time interaction only neared significance in this analysis, *F*(1, 80) = 3.44, *p* = .067, $\eta p^2$ = .04.

None of the three interaction effects of interest reached significance for any of the other working memory tasks. (See Table 4 for means and standard deviations and Table 5 for a summary of the ANOVA results.) For the 1-Back task, the three way Group × Distraction × Time interaction neared significance, F(2, 80) = 2.75, p = .07, $\eta p^2$ = .06. As shown in Figure 2, when no distractions were present, the control participants demonstrated an improvement in their 1-Back score from baseline (M = 14.20, SD = 1.26) to retest (M = 14.93, SD = .26) in contrast to college students with ADHD, whose scores were fairly stable from baseline (M = 14.73, SD = .46) to retest (M = 14.67, SD = 1.05). In the presence of auditory distractions, both participants without ADHD (baseline: M = 14.85, SD = .38; retest: M =14.77, SD=.60) and those with ADHD(baseline: M = 14.57, SD = .65; retest: M = 14.36, SD = .84) declined slightly across the two testing sessions. Finally, when retesting occurred in the presence of visual distractions, control participants declined from baseline (M = 14.86, SD = .36) to retest (M = 14.64, SD = .63), whereas students with ADHD improved (baseline: M = 14.33, SD = 1.45; retest: M = 14.73, SD = .59).

## Discussion

The results of Experiment 1 suggest that college students with ADHD demonstrate less efficient auditory working memory than their nonaffected peers. This effect emerged on only one of two auditory working memory measures, the DS test. Students with ADHD performed more poorly than those without ADHD when the DS task involved a working memory component (DS backward), but not when it assessed only simple auditory attention capacity (DS forward). In addition, college students with ADHD did not show a significant practice effect across the two testing sessions for DS forward, whereas the scores of control participants did improve across time on this test. Contrary to expectations, our young adult college students with ADHD did not evidence deficits in their visualspatial working memory relative to controls based on either their baseline scores or the practice effects they demonstrated from baseline to retest.

In examining the effect of an auditory or a visual distraction on various working memory tasks, neither type of distraction interfered significantly with participants' visual or auditory working memory. The one exception was a near-significant three-way Group × Time × Distraction interaction on the 1-Back test. During this visual working memory task, in the absence of distraction, controls demonstrated a practice effect, whereas the retest scores of students with ADHD remained stable. The presence of an auditory distraction at retest interfered with the visual working memory of both groups compared to the distraction-free baseline, whereas only the controls were vulnerable to a visual distraction at retest. Instead, the 1-Back scores of the ADHD group improved when they completed their second testing session in the presence of a visual distraction.

## EXPERIMENT 2

Experiment 2 addressed the issue of whether a brief intervention would improve working memory in young adult college students with ADHD. We hypothesized that students with ADHD would show improvements in their working memory with the introduction of a simple intervention, but that the intervention would have no effect on the working memory of their non-ADHD peers.

### Method

#### Participants

The same 86 individuals (ADHD: n = 44; controls: n = 42) who participated in Experiment 1 also participated in Experiment 2.

#### Materials

*Letter-Number Sequencing (LNS).* The LNS subtest from the Wechsler Memory Scale–Third Edition (Wechsler, 1997) involves the examiner reading a series of intermixed letters and single digits aloud at a rate of one item per second. The participant verbally reports the numbers in numerical order, followed by letters in alphabetical order. Sequences begin with three items (two letters and one number or two numbers and one letter) and become increasingly longer until the participant fails all three trials of a given sequence length.

*Conners' Continuous Performance Test (CPT).* During the CPT participants watch a long sequence of letters appear individually on a computer screen. They hit the space bar as quickly as they can whenever a letter appears, unless the letter is an X, in which case they withhold their response. Across the 20-min-long task, the computer varies the rate of presentation of stimuli. Both omissions (failing to respond to a letter other than an X) and commissions (responding to an X) count as errors. The computer also records reaction times, variability in performance as the test progresses, and perseverative response tendencies (Conners, 2000).

#### Procedure

During the same second testing session when participants completed the four working memory tests from Experiment 1 in the presence or absence of distractions, random assignment determined which of two intervention conditions participants experienced. Distractions were discontinued, and participants completed two new tests: LNS (auditory working memory) and the Conner's CPT (visual attention). Half of the participants (intervention condition: $n = 43$) completed these tests while playing with a Tangle Puzzle Junior. The remaining participants (no intervention condition: $n = 43$) completed the same two tests in the absence of this simple intervention. Participants in the two intervention conditions were statistically equivalent in age, $F(1, 84)<1$, and in their gender distribution, $x^2(N = 86, 1) < 1$. ADHD participants in the two intervention conditions were equally symptomatic as assessed by the IRS and the CAARS ADHD Index. (See Table 6.)

## Results

A 2 (Group: ADHD versus control) × 2 (Intervention Condition: intervention versus none) between groups ANOVA on scores from the LNS test and a similar multivariate analysis that included omission error, commission error, reaction time, variability, and perseveration scores from the CPT evaluated whether college students with ADHD benefited from the Tangle Puzzle Junior intervention (see Table 7).

On the LNS test, the two groups performed similarly to each other, group main effect, $F(1, 84) < 1$, $\eta p^{2} < .01$. Overall, the intervention interfered significantly with participants' auditory working memory [intervention condition main effect, $F(1, 84) = 4.15$, $p < .05$, $\eta p^{2} = .05$], and this interference was similar in magnitude regardless of whether participants were diagnosed with ADHD or not [Group × Intervention Condition interaction, $F(1, 84) < 1$, $\eta p^{2} < .01$]. Thus, contrary to expectations, those with ADHD did not benefit from the Tangle Puzzle Junior intervention on this test.

Similar results emerged for the CPT. ADHD diagnosis did not affect the number of omission errors, $F(1, 78) = 1.54$, $p = .22$, $\eta p^2 = .02$, the number of commission errors, $F(1, 78) < 1$, $\eta p^2 < .01$, participants' hit reaction time, $F(1, 78) < 1$, $\eta p^2 < .01$, or participants' variability across time, $F(1, 78) < 1$, $\eta p^2 = .01$, during this visual attention and vigilance test (multivariate group main effect, $F(5, 74) < 1$, $\eta p^2 = .05$). Participants with ADHD did make somewhat more perseverative responses than controls, although this result only neared statistical significance, $F(1, 78) = 3.30$, $p = .07$, $\eta p^2 = .04$. Unlike for LNS, the intervention did not negatively affect CPT scores [multivariate intervention condition main effect, $F(5, 74) < 1$, $\eta p^2 = .10$; all univariate intervention condition $F$s $< 3$, all $\eta p^2 < .036$], nor did the intervention differentially impact the performances of young adult students with and without ADHD [multivariate Group × Intervention Condition interaction, $F(5, 74) = 1.18$, $\eta p^2 = .04$; all univariate Group Intervention Condition interaction $F$s $< 2$, all $\eta p^2 < .022$].

## Discussion

The purpose of Experiment 2 was to assess the effects of a tactile intervention on both the auditory working memory and the visual attention of young adult college students with ADHD. Although we expected that the intervention would aid those with ADHD, results indicated that the intervention interfered with the auditory working memory of both participants with and those without ADHD and did not significantly impact the visual attention of either group.

## POST HOC: ADDITIONAL ANALYSES

Across most of the working memory measures included in this study, college students with ADHD did not perform significantly differently from their nonaffected peers, were not differentially distracted by the presence of irrelevant auditory or visual information, and did not benefit from a simple intervention. At the same time, on self-report measures, our participants with ADHD reported significantly more ADHD symptoms than our participants without an ADHD diagnosis. To explore the relationships between self-reported ADHD symptoms and working memory, as well as distractibility we ran two series of correlational analyses on the data from our ADHD participants.

First, we examined the correlations between scores on several self-report measures of ADHD symptoms (i.e., selected CAARS subscales and the IRS) and performance on the eight working memory measures at baseline. We found very limited correlations (see Table 8). For both DS forward and the more difficult PASAT condition, participants with ADHD who described themselves as more inattentive on the CAARS actually performed better than those with less self-reported inattention. In contrast, participants with ADHD who described themselves as experiencing more internal restlessness in their everyday lives performed more poorly on the 1-Back subtest. None of the other correlations reached statistical significance.

Second, for those ADHD participants who experienced either the auditory or the visual distraction, we calculated the correlations between the same self-report measures and participants' retest– baseline difference scores across each working memory measure. Again, only a limited number of correlations reached significance. (See Table 9.) ADHD participants who described themselves as more internally restless or more inattentive demonstrated less distractibility on the 1-Back and 2-Back than those participants with ADHD who described themselves as less restless or less inattentive. Similarly, ADHD participants who indicated more difficulties with hyperactivity evidenced less interference from distractions on the DS backward subtest than those who described themselves as having fewer hyperactive symptoms. Conversely, those who described themselves as more emotional labile were more vulnerable to distractions on DS backwards than those who declared less emotional lability.

## GENERAL DISCUSSION

In Experiment 1, we hypothesized that college students with ADHD would be impaired on tests of both auditory and visual-spatial working memory relative to other college students their age without ADHD. Results showed that only DS, a test of auditory attention and working memory, was sensitive to deficits in our young adults with ADHD and that differences between participants with and those without ADHD were only apparent when the task involved a working memory component and when they had an opportunity to benefit from prior experience with the test.

Although these findings do reflect working memory deficits in young adult college students with ADHD, we expected larger and more pervasive group differences between our ADHD and non-ADHD participants based on the past literature (see Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005, for a meta-analysis). Several factors may have limited our ability to document a broader range of ADHD-related working memory deficits in our study. First, we focused our study on college students. These young adults may not be representative of the general population of their same-age peers with ADHD. Second, we did not ask participants to alter their medication schedule during their participation in the study. Previous research has demonstrated that stimulant medication improves attention and visual-spatial working memory (Mehta, Calloway, & Sahakian, 2000; Mehta, Owen, et al., 2000; Turner et al., 2005). Because many of our participants may have taken medications prior to their testing session, medication effects may have masked underlying working memory deficits in the ADHD group. Third, there is very limited longitudinal research that examines changes in working memory associated with increasing age in individuals with ADHD. Vuontela and colleagues (2003) found that both auditory and visual-spatial working memory improve as typically developing children mature from age 6 to age 10. Because this result suggests functional maturation of underlying cognitive processes and brain areas with age, many of our ADHD participants may have outgrown some or all of their working memory deficits by the time they volunteered for our study as young adults. One argument against this explanation is that our participants continued to endorse significant ongoing symptoms of ADHD on self-report questionnaires, suggesting that, at least subjectively, they perceived themselves as currently struggling with inattention, distractibility and hyperactivity.

Taking these three limitations into account, the deficits in auditory working memory documented in our study become even more impressive. Despite being a select sample of successful young adult college students, many of whom were likely being treated with psychostimulant medications, our ADHD participants still demonstrated impairments in their auditory working memory at baseline and showed less ability to benefit from prior experience with the test when they returned two weeks later than their non-ADHD peers. Because auditory working memory is critical to success in college classrooms as well as in professional settings, these results suggest that even the most high-functioning young adults with ADHD are at a disadvantage compared to their nonaffected peers and may have to work harder to achieve at a similar level as others without ADHD.

Our second hypothesis was that both auditory and visual distractions would interfere more with the working memory of college students with ADHD than of those without the disorder regardless of the auditory or visual-spatial nature of the task. Although only nearing significance, results demonstrated that the visual working memory of both groups decreased in the presence of an auditory distraction. Previous research has indicated that auditory stimuli that have high linguistic content impair cognition and increase hyperactivity in individuals with ADHD (Zentall & Shaw, 1980). Because our auditory distraction involved conversations between college students, the interference we found for the ADHD group was not surprising. However, unlike in past studies, our auditory distraction did not differentially influence the ADHD group but, rather, reduced the working memory capacity of all participants. Perhaps this was due to the challenging nature of our N-Back task. Consistent with this explanation, Zentall and Shaw (1980) found similar degrees of decline in the scores earned by groups of children with and without ADHD in the presence of classroom noise when the auditory task they were completing was novel and challenging.

Interestingly, visual distraction had an unexpected effect on the visual working memory of our young adults with ADHD. Although only a trend in the data, the presence of a computer screen displaying photos of college students interfered with the visual working memory of the control group, whereas our young adults with ADHD evidenced an improvement in their working memory in the presence of this visual distraction. Although this finding was contrary to our hypothesis, these results are consistent with the optimal stimulation theory (Zentall, 1983; Zentall & Shaw, 2005) and its application to individuals with ADHD. Perhaps the introduction of the visual distraction served to increase the amount of stimulation in the testing environment, moving participants with ADHD closer to their optimal level and having a positive impact on their visual working memory. Leung, Leung, and Tang (2000) documented an improvement in auditory attention in children with ADHD in the presence of external stimulation, and our results suggest that introducing a visual distraction might positively impact the visual attention of young adult college students with ADHD as well.

The results of Experiment 2 did not support our hypothesis that college students with ADHD would show improvements in their working memory with the introduction of a simple intervention. Instead, the auditory working memory of both groups declined when playing with a Tangle Puzzle Junior, and manipulating the toy did not impact the visual attention of either group. This result contrasts with Kercood et al.’s (2007) previous findings, but several methodological differences may explain these inconsistent results. Because we were interested in the effect of the Tangle Puzzle Junior intervention on attention and working memory rather than on distractibility, we discontinued any distractions prior to administering the tests that the participants completed while playing with the toy. Thus, it is possible that the Tangle Puzzle Junior helps individuals with ADHD filter out distractions but does not have a significant direct effect on working memory in their absence. Another major difference between the Kercood study and the current one is participant age. Our college students with ADHD have had years of experience in educational environments and may have established strategies for focusing their attention when necessary, thus minimizing any benefit the Tangle Puzzle Junior intervention may have offered if they were younger and less experienced with managing their ADHD symptoms.

Because our participants with ADHD described themselves as experiencing significant ADHD symptomatology but showed rather limited working memory deficits and distractibility on formal neuropsychological measures, we ran post hoc analyses to examine the relationship between self-reported symptoms and objective test performance. Interestingly, we found only limited correlations, and many of the correlations that reached statistical significance suggested that college students with ADHD who perceived themselves as more symptomatic instead outperformed their ADHD peers on a measure of their auditory capacity and were less vulnerable to distractions. The two positive relationships we identified between self-reported ADHD symptoms and objective test performance showed that participants with ADHD who described themselves as experiencing more internal restlessness performed more poorly on the 1-Back subtest than those who indicated that they are less internally restless. Additionally, those who described themselves as more emotional labile were more vulnerable to distractions on the DS backwards test than those who clamied less emotional lability.

Only a few studies have examined the relationship between self-reported ADHD symptoms and working memory test scores in adults with ADHD (Dowson et al., 2007; Mackin & Horner, 2005). Mackin and Horner (2005) did not find a significant correlation between adults' descriptions of their ADHD symptoms on the Wender–Utah scale and their scores on several tests of attention, including the DS test. Although the DS test was one of the measures on which we did find a significant correlation in the predicted direction, the use of the CAARS (which inquires about current ADHD symptomotology) in our study as opposed to the use of the Wender–Utah (which asks about past childhood ADHD symptoms) in the the Mackin and Horner study may explain why we were able to document relationships when they did not. Interestingly, our findings that internal restlessness correlated with visual working memory on the N-Back correspond nicely with those of Dowson et al. (2007), who also documented correlations between self-reported impulsivity and emotive behavior and visual-spatial working memory, even though they used different subjective and objective measures. At the same time, the large differences in the subjective self-reported ADHD symptoms of our college students with and without ADHD, together with the generally similar scores the two groups earned on most working memory measures both at baseline and in the presence of distractions, suggest that students with ADHD might hold negative self-perceptions due to their diagnosis and/or to their past symptomatology even when objective measures indicate that they are doing fairly well in terms of their attention and ability to effectively filter distractions. This possibility is strengthened by the significant negative correlations we found between several questionnaire scales and test scores.

One potential explanation for the limited and, at times, nonintuitive relationships we found between subjective symptom severity and objective test performance is that our young adults with ADHD described their symptoms based on their unmedicated state but took the tests and earned their objective scores while medicated. Similarly, despite instructions to describe their current state of attention, distractibility, hyperactivity, and restlessness on the CAARS and the IRS, our group of participants with ADHD may have relied on or been influenced by their past symptomatology when formulating their answers. To the extent that their ADHD has evolved over time or is amenable to medications, either of these factors would reduce the correlation between subjective and objective measures.

Because our study was not designed to address the relationships between subjective self-perceptions and objective test scores, our data cannot differentiate which of these possibilities might best explain our results. However, our findings do suggest that future research designed to investigate this issue more systematically could yield interesting information about the relationship between subjective and objective attention in ADHD. Gaining a better understanding of this issue is vital, as past studies have demonstrated that self-perceptions can affect choice of task, goal-setting, effort, persistence, and other behaviors that ultimately influence success (Dunn & Shapiro, 1999; Friedman et al., 2003; Hoza, Pelham, Waschbusch, Kipp, & Owens, 2001; Hoza et al., 2004). This, together with our findings of rather limited differences in actual attention and working memory abilities between our college students with and without ADHD, raises the possibility that self-perceptions may be driving, or at the very least mediating, the effect of being diagnosed with ADHD on college student success.

## REFERENCES

Adams, R., Finn, P., Moes, E., Flannery, K., & Rizzo A. S. (2009). Distractibility in Attention/Deficit/Hyperactivity Disorder (ADHD): The virtual reality classroom. *Child Neuropsychology*, *15*, 120–135.

Advokat, C. (2010). What are the cognitive effects of psychostimulant medications? Emphasis on adults with attention-deficit/hyperactivity disorder (ADHD). *Neuroscience and Biobehavioral Reviews*, *34*, 1256–1266.

Awh, E., Jonides, J., Smith, E. E, Schumcher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from PET. *Psychological Science*, *7*, 25–31.

Baddeley, A. D. (1986). *Working Memory*. Oxford, UK: Oxford University Press.

Baddeley, A. D. (2003) Working memory and language: An overview. *Journal of Communication Disorders*, *36*, 189–208.

Barkley, R. A. (1998). *Attention-deficit hyperactivity disorder: A handbook for diagnosis and treatment* (2nd ed.). New York, NY: Guilford Press.

Barkley, R. A., Murphy, K., & Kwasnik, D. (1996). Motor vehicle driving competencies and risks in teens and young adults with attention deficit hyperactivity disorder. *Pediatrics*, *98*, 1089–1095.

Berti, S., & Schröger, E. (2003). Working memory controls involuntary attention switching: Evidence from an auditory distraction paradigm. *European Journal of Neuroscience*, *17*, 1119–1122.

Biederman, J., Petty, C. R., Ball, S. W., Fried, R., Doyle, A. E., Cohen, D., et al. (2009). Are cognitive deficits in attention deficit/hyperactivity disorder related to the course of the disorder? A prospective controlled follow-up study of grown up boys with persistent and remitting course. *Psychiatry Research*, *170*, 177–182.

Blase, S. L., Gilbert, A. N., Anastopoulos, A. D., Costello, E. J., Hoyle, R. H., Swartzwelder, et al. (2009). Self-reported ADHD and adjustment in college: Cross-sectional and longitudinal findings. *Journal of Attention Disorders*, *13*, 297–309.

Clark, L., Blackwell, A. D., Aron, A. R., Turner, D. C., Dowson, J., Robbins, T. W., et al. (2007). Association between response inhibition and working memory in adult ADHD: A link to right frontal cortex pathology? *Biological Psychiatry*, *61*(12), 1395–1401.

Cohen, J. D., Forman, S. D., Braver, T. S., Casey, B. J., Servan-Schreiber, D., & Noll, D. C. (1994). Activation of prefrontal cortex in a nonspatial working memory task with functional MRI. *Human Brain Mapping*, *1*, 293–304.

Cohen, J. D., Perlstein, W. M., Braver, T. S., Nystrom, L. E., Noll, D. C., Jonides, J., et al. (1997). Temporal dynamics of brain activation during a working memory task. *Nature*, *386*, 604–608.

Conners, C. (2000). *Conners' Continuous Performance Test II: Technical guide*. Toronto, Canada: Multi-Health Systems.

Conners, C., Ehrhard, D., & Sparrow, D. (1999). *CAARS Adult ADHD Rating Scales*. New York, NY: MHS.

Corbett, B., & Stanczak, D. E. (1999). Neuropsychological performance of adults evidencing Attention-Deficit Hyperactivity Disorder. *Archives of Clinical Neuropsychology*, *14*, 373–387.

Davis-Berman, J. L., & Pestello, F. G. (2010).Medicating for ADD/ADHD: Personal and social issues. *International Journal of Mental Health Addiction*, *8*, 482–492.

Dipeolu, A. O. (2011). College students with ADHD: Prescriptive concepts for best practices in career development. *Journal of Career Development, 38,* 408–427.

Dowson, J. H., Blackwell, A. D., Turner, D. C., Harvey, E., Malhotra, T., Robbins, T. W., et al. (2007). Questionnaire ratings of attentiondeficit/hyperactivity disorder (ADHD) in adults are associated with spatial working memory. *European Psychiatry, 22,* 256–263.

Dowson, J. H., McLean, A., Bazanis, E., Toone, B., Young, S., Robbins, T. W., et al. (2004). Impaired spatial working memory in adults with Attention Deficit/ Hyperactivity Disorder: Comparisons with performance in adults with borderline personality disorder and in control subjects. *Acta Psychiatrica Scandanivica*, *110*, 45–54.

Dunn, P. B., & Shapiro, S. K. (1999). Gender differences in the achievement goal orientation of ADHD children. *Cognitive Therapy and Research*, *23*, 327–344.

DuPaul, G. J., Weyandt, L. L., O'Dell, S. M., & Varejao, M. (2009). College students with ADHD: Current status and future directions. *Journal of Attention Disorders*, *13*, 234–250.

Egeland, J. (2007). Differentiating attention deficit in
adult ADHD and schizophrenia. *Archives of Clinical Neuropsychol*ogy, *22*, 763–71.

Friedman, S. R., Rapport, L. J., Lumley, M., Tzelepis, A., VanVoorhis, A., Stettner, L., et al. (2003). Aspects of social and emotional competence in adult attention deficit/ hyperactivity disorder. *Neuropsychology*, *17*, 50–58.

Fuchs, T., Birbaumer, N., Lutzenberger, W., Gruzelier, J. H., & Kaiser, J. (2003). Neurofeedback treatment for Attention-Deficit/Hyperactivity Disorder in children: A comparison with methylphenidate. *Applied Psychophysiology Biofeedback*, *28*, 1–12.

Gronwall, D. M., & Sampson, H. (1974). *The psychological effects of concussion*. Auckland, New Zealand: Aukland University Press.

Hale, T. S., Bookheimer, S., McGough, J. J., Phillips, J. M., & McCracken, J. T. (2007). Atypical brain activation during simple & complex levels of processing in adult ADHD: An fMRI study. *Journal of Attention Disorders, 10,* 1–16.

Heiligenstein, E. U., Guenther, G., Levy, A., Savino, F., & Fulwiler, J. (1999). Psychological and academic functioning in college students with attention deficit hyperactivity disorder. *Journal of American College Health, 47,* 181–185.

Higginbotham, P., & Bartling, C. (1993). The effects of sensory distractions on short-term recall of children with Attention Deficit-Hyperactivity Disorder versus normally achieving children. *Bulletin of the Psychonomic Society*, *31*, 507–510.

Hoza, B., Gerdes, A. C., Hinshaw, S. P., Arnold, L. E., Pelham, W. E., Molina, B. S. G., et al. (2004). Selfperceptions of competence in children with ADHD and comparison children. *Journal of Consulting and Clinical Psychology*, *72*, 382–391.

Hoza, B., Pelham, W. E., Waschbusch, D. A., Kipp, H., & Owens J. (2001). Academic task persistence of normally-achieving ADHD and control boys: Performance, self- evaluations, and attributions. *Journal of Consulting and Clinical Psychology*, *69*, 271–283.

Janusis, G. M., & Weyandt, L. L. (2010). An exploratory study of substance use and misuse among college students with and without ADHD and other disabilities. *Journal of Attention Disorders*, *14*, 205–215.

Karatekin, C., & Asarnow, R. F. (1998). Working memory in childhood-onset schizophrenia and Attention-Deficit⁄Hyperactivity Disorder (ADHD). *Psychiatry Research*, *80*, 165–176.

Kercood, S., & Grskovic, J. (2010). Reducing the effects of auditory and visual distraction on the math performances of students with Attention Deficit Hyperactivity Disorder. *Australian Journal of Learning Difficulties, 15*, 1–11.

Kercood, S., Grskovic, J., Lee, D. L., & Emmert, S. (2007). Effects of fine motor movement and tactile stimulation on the math problem solving of students with attention problems. *Journal of Behavioral Education*, *16*, 303–310.

Klingberg, T., Fossberg H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, *24*, 781–791.

Leung, J. P., Leung, P. W. L., & Tang, C. S. K. (2000). A vigilance study of ADHD and control children: Event rate and extra-task stimulation. *Journal of Developmental and Physical Disabilities*, *12*, 187–201.

Mackin R. S., & Horner, M. D. (2005). Relationship of the Wender Utah Rating Scale to objective measures of attention. *Comprehensive Psychiatry*, *46*, 468–471.

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attentiondeficit⁄hyperactivity disorder. *Journal of the American Academy of Child Adolescence Psychiatry*, *44*, 377–384.

McLean, A., Dowson, J., Toone, B., Young, S., Bazanis, E., Robbins, T. W., et al. (2004). Characteristic neurocognitive profile associated with adult attentiondeficit⁄hyperactivity disorder. *Psychological Medicine*, *34*, 681–692.

Mehta, M. A., Calloway, P., & Sahakian, B. J. (2000). Amelioration of specific working memory deficits by methylphenidate in a case of adult attention-deficit⁄hyperactivity disorder. *Journal of Psychopharmacology*, *14*, 299–302.

Mehta, M. A., Owen, A. M., Sahakian, B. J.,Mavaddat, N., Pickard, J. D., & Robbins, T. W. (2000). Methylphenidate enhances working memory by modulating discrete frontal and parietal lobe regions in the human brain. *Journal of Neuroscience, 20*(RC65), 1–6.

Murphy, K. R., Barkley, R. A., & Bush, T. (2001). Executive functioning and olfactory identification in young adults with attention deficit-hyperactivity disorder. *Neuropsychology*, *15*, 211–220.

Norvilitis, J. M., Sun, L., & Zhang, J. (2010). ADHD symptomatology and adjustment to college in China and the United States. *Journal of Learning Disabilities*, *43*, 86–94.

Norwalk,K., Norvilitis, J.M., &MacLean,M.G. (2009). ADHD symptomatology and its relationship to factors associated with college adjustment. *Journal of Attention Disorders*, *13*, 251–258.

Ross, R. G., Harris, J. G., Olincy, A., & Radant A. (2000). Eye movement task measures inhibition and spatial working memory in adults with schizophrenia, ADHD, and a normal comparison group. *Biological Psychiatry*, *48*, 197–203.

Schweitzer, J. B., Hanford, R. B., & Medoff, D. R. (2006). Working memory deficits in adults with ADHD: Is there evidence for subtype differences? *Behavioral and Brain Functions*, *2*, 43.

Shallice, T. (1988). *From neuropsychology to mental structure*. New York, NY: Cambridge University Press.

Shekim, W., Asarnow, R., Hess, E., Zaucha, K., & Wheeler,N. (1990).An evaluation of Attention Deficit Disorder–Residual Type. *Comprehensive Psychiatry*, *31*, 416–425.

Smith, E. E., & Jonides, J. (1997). Working memory: A view from neuroimaging. *Cognitive Psychology*, *33*, 5–42.

Söderlund, G., Sikström, S., & Smart, A. (2007). Listen to the noise: Noise is beneficial for cognitive performance in ADHD. *The Journal of Child Psychology and Psychiatry*, *48*, 840–847.

Swanson, H. L., & Sachse-Lee, C. (2001). A subgroup analysis of working memory in children with reading disabilities: Domain general or domain specific deficiency. *Journal of Learning Disabilities*, *34*, 249–262.

Swanson, H. L., & Siegel, L. (2001). Learning disabilities as a working memory deficit. *Issues in Education: Contributions from Educational Psychology*, *7*, 1–48.

Turner, D. C., Blackwell, A. D., Dowson, J. H., McLean, A., & Sahakian, B. J. (2005). Neurocognitive effects of methylphenidate in Adult Attention-Deficit/Hyperactivity Disorder. *Psychopharmacology*, *178*, 286–295.

Valera, E. M., Faraone, S. V., Biederman, J., Poldrack, R. A., & Seidman, L. J. (2005). Functional neuroanatomy of working memory in adults with attention deficit/ hyperactivity disorder. *Biological Psychiatry*, *57*, 439–447.

Vuontela, V., Steenari, M. R., Carlson, S., Koivisto, J., Fjällberg, M., & Aronen, E. T. (2003). Audiospatial and visuospatial working memory in 6–13 year old school children. *Learning and Memory*, *10*, 74–78.

Wechsler, D. (1997). *Wechsler Memory Scale* (3rd ed.). San Antonio, TX: The Psychological Corporation.

Westerberg, H., Hirvikoski, T., Forssberg, H., & Klingberg, T. (2004). Visuo-spatial working memory span: A sensitive measure of cognitive deficits in children with ADHD. *Child Neuropsychology*, *10*, 155–161.

Weyandt, L. L., & DuPaul, G. J. (2008). ADHD in college students: Developmental findings. *Developmental Disabilities Research Reviews*, *14*, 311–319.

Weyandt, L. L., Iwaszuk. W., Fulton, K., Ollerton, M., Beatty, N., Pouts, M., et al. (2003). The Internal Restlessness Scale: Performance of college students with and without ADHD. *Journal of Learning Disabilities*, *36*, 382–389.

White, J. N., Hutchens, T. A., & Lubar, J. F. (2005). Quantitative EEG assessment during neuropsychological task performance in adults with attention deficit hyperactivity disorder. *Journal of Adult Development*, *12*, 113–121.

Young, S., Morris, R., Toone, B., & Tyson, C. (2007). Planning ability in adults with attention deficit/hyperactivity disorder. *Neuropsychology*, *21*, 581–589.

Zentall, S. S. (1983). Learning environments: A review of physical and temporal factors. *Exceptional Education Quarterly*, *4*, 90–115.

Zentall, S. S. (2005). Theory- and evidence-based strategies for children with attentional problems. *Psychology in the Schools*, *42*, 821–836.

Zentall, S. S., & Shaw, J. H. (1980). Effects of classroom noise on performance and activity of second grade hyperactive and control children. *Journal of Educational Psychology*, *8*, 830–840.

**TABLE 1**
Demographic characteristics of the control and ADHD participants overall

| *Characteristic* | *Control group (n = 42)* | *ADHD group (n = 44)* |
|---|---|---|
| Age | 19.57 (1.38) | 20.09 (1.80) |
| % male | 33% | 37% |
| % White[a] | 93% | 98% |
| IRS total* | 74.18 (15.59) | 106.65 (15.26) |
| ADHD index* | 10.45 (4.16) | 18.12 (3.65) |

*Note.* IRS = Internal Restlessness Scale, ADHD index = score from the Conner's Adult ADHD Rating Scale. Standard deviations in parentheses.

[a] The Control group included three participants who indicated that they were not White (one who was Hispanic and two who were Asian). The ADHD group included one participant who identified herself as Asian.

*The control group and ADHD group differed significantly ($p < .001$).

**TABLE 2**
Demographic characteristics of the control and ADHD participants by Experiment 1 distraction condition

| | *Control group* | | | *ADHD group* | | |
|---|---|---|---|---|---|---|
| *Characteristic* | *No distraction (n = 15)* | *Visual distraction (n = 14)* | *Auditory distraction (n = 13)* | *No distraction (n = 15)* | *Visual distraction (n = 15)* | *Auditory distraction (n = 14)* |
| Age | 18.67 (1.05) | 19.64 (1.50) | 20.54 (0.88) | 20.00 (2.14) | 20.27 (1.53) | 20.00 (1.80) |
| % male | 27% | 43% | 31% | 27% | 40% | 50% |
| % White[a] | 100% | 92% | 85% | 100% | 100% | 93% |
| IRS total* | 77.07 (15.84) | 72.46 (16.25) | 72.77 (15.48) | 107.50 (17.50) | 101.21 (11.56) | 112.00 (15.35) |
| ADHD index* | 9.64 (3.77) | 11.14 (4.94) | 10.58 (3.75) | 17.67 (4.64) | 18.21 (3.09) | 18.54 (3.10) |

*Note.* IRS = Internal Restlessness Scale, ADHD Index = score from the Conner's Adult ADHD Rating Scale. Standard deviations in parentheses.

[a] The Control group included three participants who indicated that they were not White (one who was Hispanic and two who were Asian). The ADHD group included one participant who identified herself as Asian.

*The ADHD and control groups differed significantly (both $ps < .001$), but ADHD participants were matched in IRS Score and ADHD Index across the three distraction conditions, as were controls.

**TABLE 3**
Mean scores on the four primary working memory tests at baseline in Experiment 1

| | *Control group* | | | *ADHD group* | | |
|---|---|---|---|---|---|---|
| *Test* | *Easy* | *Moderate* | *Hard* | *Easy* | *Moderate* | *Hard* |
| Digit span | 11.36 (1.96) | | 8.24 (2.35) | 11.30 (2.06) | | 7.16 (2.13) |
| PASAT | 50.19 (7.64) | | 39.43 (10.29) | 47.98 (10.00) | | 35.32 (11.39) |
| Spatial span | 9.67 (1.59) | | 9.12 (1.38) | 9.36 (1.91) | | 8.66 (1.40) |
| N-back | 14.62 (0.85) | 14.14 (1.35) | 12.38 (2.19) | 14.55 (0.95) | 13.89 (1.67) | 12.34 (1.96) |

*Note.* Standard deviations in parentheses.

## TABLE 4

Mean scores at baseline and retest for participants in each diagnosis group and distraction condition

| | *Control group* | | | | | | *ADHD group* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *No distraction condition* | | *Visual distraction condition* | | *Auditory distraction condition* | | *No distraction condition* | | *Visual distraction condition* | | *Auditory distraction condition* | |
| *Test* | *Baseline* | *Retest* | *Baseline* | *Retest* | *Baseline* | *Retest* | *Baseline* | *Retest* | *Baseline* | *Retest* | *Baseline* | *Retest* |
| DS fwd | 11.9 (1.8) | 12.7 (1.9) | 10.4 (1.9) | 12.0 (1.6) | 11.8 (1.9) | 12.1 (2.2) | 12.5 (1.5) | 12.3 (2.4) | 10.4 (1.9) | 10.5 (2.5) | 10.9 (2.7) | 11.0 (2.2) |
| DS bwd | 8.1 (2.3) | 7.7 (2.8) | 8.6 (3.0) | 8.1 (1.9) | 8.1 (1.7) | 8.8 (3.4) | 7.9 (2.1) | 9.3 (2.4) | 6.4 (1.5) | 6.6 (1.8) | 7.2 (2.6) | 8.8 (3.8) |
| PASAT 3.0 | 51.3 (7.5) | 57.9 (2.0) | 50.9 (6.1) | 55.4 (5.0) | 48.2 (9.3) | 55.2 (5.1) | 51.3 (6.7) | 57.2 (3.0) | 44.9 (11.3) | 52.7 (6.4) | 47.7 (11.0) | 53.1 (6.7) |
| PASAT 2.0 | 40.7 (8.6) | 48.1 (6.8) | 38.2 (13.7) | 48.9 (9.5) | 39.2 (8.2) | 46.1 (11.0) | 39.1 (9.2) | 47.1 (9.1) | 29.8 (10.6) | 38.9 (11.7) | 37.1 (12.7) | 43.8 (10.9) |
| SS fwd | 10.0 (1.5) | 9.9 (1.8) | 10.0 (1.2) | 10.3 (1.2) | 9.1 (2.0) | 9.8 (2.0) | 9.7 (1.8) | 10.3 (1.8) | 9.5 (1.5) | 9.5 (1.3) | 8.9 (2.4) | 8.9 (2.1) |
| SS bwd | 9.0 (1.4) | 8.7 (1.6) | 9.0 (1.5) | 9.0 (1.6) | 9.1 (1.4) | 8.4 (2.7) | 8.4 (1.8) | 8.8 (1.8) | 8.8 (1.4) | 8.7 (1.3) | 8.8 (1.0) | 8.5 (2.5) |
| 1-Back | 14.2 (1.3) | 14.9 (0.3) | 14.9 (0.4) | 14.6 (0.6) | 14.8 (0.4) | 14.8 (0.6) | 14.7 (0.5) | 14.7 (1.0) | 14.3 (1.4) | 14.7 (0.6) | 14.6 (0.6) | 14.4 (0.8) |
| 2-Back | 14.1 (1.1) | 14.4 (1.3) | 13.9 (1.9) | 14.1 (2.1) | 14.4 (0.8) | 14.2 (1.0) | 13.9 (1.4) | 14.3 (1.1) | 14.4 (0.7) | 14.4 (1.1) | 13.3 (2.4) | 13.5 (2.7) |
| 3-Back | 12.0 (2.1) | 12.4 (1.4) | 12.9 (2.4) | 13.4 (1.8) | 12.4 (2.2) | 12.9 (2.0) | 12.6 (1.9) | 12.7 (1.8) | 12.4 (1.8) | 12.6 (1.3) | 12.0 (2.3) | 12.5 (2.3) |

*Note.* Fwd = forward; bwd = backward. Standard deviations in parentheses.

## TABLE 5

Summary of the interaction effects of interest in the Experiment 1 analysis of variance

| | *Group × Time* | | | *Distraction × Time* | | | *Group × Distraction × Time* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Test* | *F* | *df* | *p* | *F* | *df* | *p* | *F* | *df* | *p* |
| Digit span fwd | 7.42 | 1,80 | <.01 | 1.74 | 2,80 | .18 | 1.37 | 2,80 | .26 |
| Digit span bwd | 3.44 | 1,80 | .07 | 1.45 | 2,80 | .24 | < 1 | 2,80 | .72 |
| PASAT 3.0 | < 1 | 1,80 | .83 | < 1 | 2,80 | 1.0 | < 1 | 2,80 | .42 |
| PASAT 2.0 | < 1 | 1,80 | .83 | 1.11 | 2,80 | .33 | < 1 | 2,80 | .88 |
| Spatial span fwd | < 1 | 1,80 | .76 | < 1 | 2,80 | .88 | < 1 | 2,80 | .50 |
| Spatial span bwd | 1.02 | 1,80 | .32 | < 1 | 2,80 | .40 | < 1 | 2,80 | .65 |
| 1-Back | < 1 | 1,80 | .67 | 1.22 | 2,80 | .30 | 2.75 | 2,80 | .07 |
| 2-Back | < 1 | 1,80 | .70 | < 1 | 2,80 | .72 | < 1 | 2,80 | .76 |
| 3-Back | < 1 | 1,80 | .53 | < 1 | 2,80 | .79 | < 1 | 2,80 | .99 |

*Note.* Fwd = forward; bwd = backward.

## TABLE 6

Demographic characteristics of the control and ADHD participants by Experiment 2 intervention condition

| | *Control group (n = 42)* | | *ADHD group (n = 44)* | |
|---|---|---|---|---|
| *Characteristic* | *No intervention (n = 21)* | *Intervention (n = 21)* | *No intervention (n = 22)* | *Intervention (n = 22)* |
| Age | 19.76 (1.55) | 19.38 (1.20) | 20.14 (1.73) | 20.05 (1.91) |
| % male | 33% | 33% | 45% | 32% |
| % White | 95% | 90% | 100% | 95% |
| IRS total* | 73.00 (13.85) | 75.24 (17.29) | 105.29 (17.31) | 108.16 (12.91) |
| ADHD index* | 10.05 (4.87) | 10.85 (3.38) | 17.19 (3.56) | 19.05 (3.58) |

*Note.* IRS = Internal Restlessness Scale, ADHD Index = score from the Conner's Adult ADHD Rating Scale. Standard deviations in parentheses.

*The ADHD and control groups differed significantly from each other (both *ps* < .001), but ADHD participants were matched in IRS Score and ADHD Index across the two intervention conditions, as were controls.

## TABLE 7

Mean scores on the two tests administered during Experiment 2 without or with the intervention

| | *Control group* | | *ADHD group* | |
|---|---|---|---|---|
| *Test measure* | *No intervention* | *Intervention* | *No intervention* | *Intervention* |
| Letter-number sequencing | 12.7 (2.6) | 11.9 (2.4) | 12.9 (2.9) | 11.4 (2.5) |
| CPT omission errors | 47.1 (4.0) | 53.7 (21.4) | 52.0 (12.8) | 57.7 (20.6) |
| CPT commission errors | 50.4 (7.4) | 53.6 (11.7) | 52.5 (12.8) | 55.1 (8.0) |
| CPT hit reaction time | 42.9 (8.5) | 42.2 (10.1) | 40.1 (8.0) | 44.6 (9.0) |
| CPT variability | 49.7 (12.3) | 49.4 (8.8) | 50.4 (13.0) | 53.2 (13.1) |
| CPT perseverations | 46.8 (2.6) | 48.7 (3.6) | 51.6 (10.1) | 55.0 (24.9) |

*Note.* CPT = Conners' Continuous Performance Test; CPT scores represent standardized T-scores (Mean = 50, *SD* = 10) based on participants' age and gender. Standard deviations in parentheses.

## TABLE 8

Correlations between CAARS subscales, internal restlessness, and baseline working memory

| *Test* | *Inattention*[a] | *Hyperactivity*[a] | *Emotional lability*[a] | *Self-concept*[a] | *ADHD index* | *Internal restlessness* |
|---|---|---|---|---|---|---|
| Digit span fwd | .34* | .00 | .00 | .11 | .15 | −.05 |
| Digit span bwd | .21 | .00 | .04 | −.06 | −.04 | −.16 |
| PASAT 3.0 | .13 | .10 | −.28 | −.13 | −.04 | .01 |
| PASAT 2.0 | .30* | .22 | −.24 | −.10 | .11 | .24 |
| Spatial span fwd | −.13 | −.15 | −.04 | .02 | −.11 | .04 |
| Spatial span bwd | .07 | −.03 | −.02 | −.07 | −.03 | −.06 |
| 1-Back | .01 | −.25 | −.11 | .08 | −.12 | −.38* |
| 2-Back | .00 | −.12 | .18 | −.08 | −.09 | .01 |
| 3-Back | .07 | −.14 | −.12 | −.11 | −.16 | −.12 |

*Note.* CAARS = Conners' Adult ADHD Rating Scale; fwd = forward; bwd = backward.

*$p < .05$.

[a] CAARS subscale.

## TABLE 9

Correlations between CAARS subscales, internal restlessness, and working memory retest–baseline difference scores

| *Test* | *Inattention*[a] | *Hyperactivity*[a] | *Emotional Lability*[a] | *Self-Concept*[a] | *ADHD Index* | *Internal Restlessness* |
|---|---|---|---|---|---|---|
| Digit span fwd | −.13 | .02 | −.19 | .00 | −.18 | .17 |
| Digit span bwd | −.11 | .31* | −.35* | .09 | −.09 | −.03 |
| PASAT 3.0 | −.08 | −.09 | .22 | −.01 | −.12 | −.11 |
| PASAT 2.0 | −.08 | .04 | .23 | −.03 | −.16 | −.18 |
| Spatial span fwd | .13 | .00 | −.11 | .05 | .02 | .05 |
| Spatial span bwd | .05 | .10 | −.10 | −.06 | −.01 | .07 |
| 1-Back | .10 | −.03 | .20 | .09 | .26 | .41** |
| 2-Back | .32* | .01 | −.14 | .04 | −.05 | .03 |
| 3-Back | −.02 | .07 | −.05 | .08 | .03 | .12 |

*Note.* CAARS = Conners' Adult ADHD Rating Scale; fwd = forward; bwd = backward.

*$p < .05$. **$p < .01$.

[a] CAARS subscale.

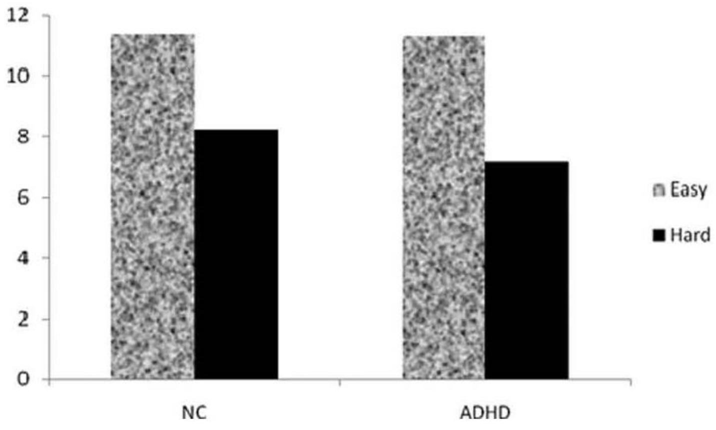

**Figure 1.** Performance of normal control participants (NC) and college students with ADHD (ADHD) on the digit span measure of auditory working memory. Digit span forward comprised the easy condition (marbled bars) and digit span backwards comprised the hard condition (solid bars). A significant interaction between group and test difficulty indicated that the two groups performed similarly when the task was easy, but college students with ADHD performed more poorly than NC when the task was more difficult.

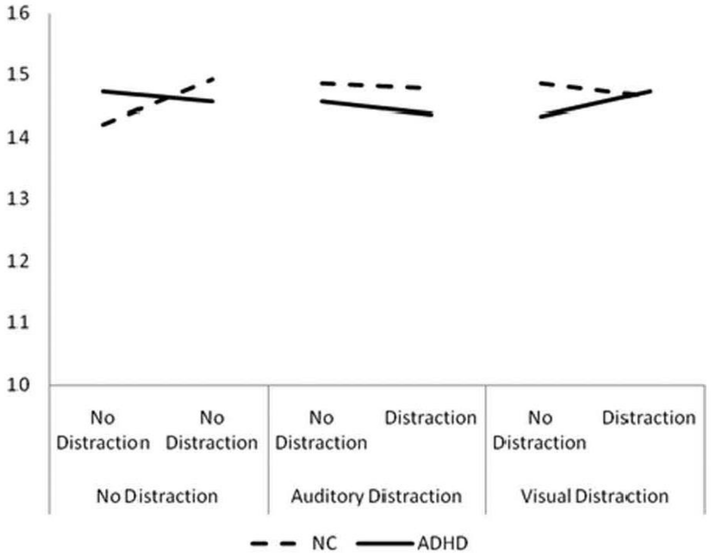

**Figure 2.** Performance of normal control participants (hashed lines) and college students with ADHD (solid lines) on the 1-Back test of visual-spatial working memory at baseline in the absence of distractions and at retest in the absence (no distraction group—left panel) or presence (auditory distraction—middle panel; visual distraction—right panel) of distractions.