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Lecture note-taking in postsecondary students with attention-deficit/hyperactivity disorder

Pooja C. Vekaria[1] · **Stephen T. Peverly**[2]

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Abstract The primary purpose of this investigation was to determine if there were differences in note-taking and test-taking in students with and without ADHD, and if there were, to examine the cognitive variables that might explain them. Participants included 22 postsecondary students with self-reported ADHD and 50 postsecondary student controls. Students took notes on a lecture, reviewed them, and took a written recall test. The independent variables were disability status, sustained attention, handwriting speed, verbal working memory, and listening comprehension. The dependent variables were quality of notes and written recall. Students with ADHD obtained lower scores on written recall and handwriting speed compared to controls, but did not differ on quality of notes, sustained attention, verbal working memory, or listening comprehension. Sustained attention and listening comprehension predicted quality of notes, and disability status, quality of notes, and listening comprehension predicted written recall.

Keywords Note-taking · Cognitive processes · ADHD · Adults

Research suggests that low academic achievement among postsecondary students is partly due to inadequate study skills (Allsopp, Minskoff, & Bolt, 2005; Crede & Kuncel, 2008; Kaminski, Turnock, Rosen, & Laster, 2006; Norwalk, Norvilitis, &

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✉ Stephen T. Peverly
stp4@tc.columbia.edu

1 Department of Psychiatry, Columbia University Medical Center, New York, USA

2 Department of Health and Behavior Studies, Teachers College, Columbia University, 525 West 120th Street, Box 120, New York, NY 10027, USA

MacLean, 2009; Reaser, Prevatt, Petscher, & Proctor, 2007). Since lecture is the dominant form of instruction beyond elementary school, and postsecondary students typically spend 80% of class time listening to lectures (Armbruster, 2009; Titsworth & Kiewra, 2004), the preferred and most prevalent method of studying in higher education is taking and reviewing lecture notes (Armbruster, 2009).

Research with typically functioning postsecondary adults has shown that taking and reviewing lecture notes is related to better test performance (Kiewra & Benton, 1988; Kiewra et al., 1991; Norton & Hartley, 1986; Peverly et al., 2007; Titsworth & Kiewra, 2004; Williams & Eggert, 2002a). Research on postsecondary adults with a disability indicates they struggle with note-taking (Maydosz & Raver, 2010; Peverly, Marcelin, & Kern, 2014b) and the cognitive variables associated with note-taking (Suritsky, 1993).

Incidence of students with disabilities in postsecondary education

Estimates of the incidence of disabilities has been increasing among students in postsecondary education from a low of 3% in 1978 (National Council on Disability, 2003) to 11–14% in more recent publications (Higher Education Research Institute, 2011; U.S. Censure Bureau, 2012). Many receive the diagnosis of ADHD after entering college (National Council on Disability, 2003).

Disabilities reported by individuals in postsecondary institutions range from hearing, speech, orthopedic, health-related, to other conditions including "hidden disabilities", which constitute the greatest increase in enrollment of individuals with disabilities in higher education (Wolf, 2001). Attention-deficit/hyperactivity disorder (ADHD), a "hidden disability", is characterized by persistent patterns of inattention, hyperactivity, or impulsivity (Barkley, 2006), which interferes with academic, occupational, and/or social functioning (American Psychiatric Association, 2000; Wolf, Simkowitz, & Carlson, 2009).

Epidemiological studies of postsecondary settings have found that 2–11% of students reported clinically significant levels of ADHD symptoms (DuPaul et al., 2001; Heiligenstein, Conyers, Berns, & Smith, 1998; Higher Education Research Institute, 2011; McKee, 2008; Norvilitis, Ingersoll, Zhang, & Jia, 2008; Pope et al., 2007; Weyandt, Linterman, & Rice, 1995). Research also indicates that postsecondary students with significant ADHD symptoms generally obtain lower GPAs, receive more special education services, are more likely to be on academic probation, and are less likely to graduate when compared to controls (Barkley, 2006; Barkley, Murphy, & Fischer, 2008; DuPaul, Weyandt, O'Dell, & Varejao, 2009; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999; Kaminski et al., 2006; Lewandowski, Lovett, Codding, & Gordon, 2008; Murphy, Barkley, & Bush, 2002; Norwalk et al., 2009; Weyandt & DuPaul, 2006; Wolf, 2001). These studies also indicate that impaired organizational and time management abilities, deficits in working memory, difficulty with goal-setting, inadequate academic coping strategies, difficulties with behavioral and emotional self-regulation, and most importantly for this investigation, study skills, may contribute to their academic difficulties. This investigation focused on students with and without ADHD and the cognitive processes associated with an important and pervasive study skill—note-taking.

Cognitive processes associated with effective note-taking

Like most academic skills, lecture note-taking is very cognitively demanding (Piolat, Olive, & Kellogg, 2005). The dominate paradigm for the development of academic skills is limited capacity processing. Contemporary views of capacity-limited cognitive processing (Marois & Ivanoff, 2005) and theories of performance in academic skills such as reading (Hulme & Snowling, 2011), writing (Berninger, 2012; McCutchen, 2000), and mathematics (Geary, 2011) strongly suggest that competence depends on the parallel activation of a hierarchy of domain-specific and higher order cognitive skills, within a limited capacity working memory. Domain specific basic skills must be sufficiently fluent or automatic so that most if not all of the limited space in working memory can be used for the application of the higher level cognitive skills needed to produce successful academic outcomes. Once lower level skills are sufficiently fluent or automatic, the quality of the outcome (e.g., reading comprehension) is strongly related to the quality of the higher level skills.

To take good lecture notes students must comprehend and hold important lecture information in verbal working memory, select and quickly transcribe the information before it is forgotten, and continue to attend to the lecture (Peverly et al., 2007). Thus, skill in lecture note-taking may be related to language comprehension, working memory, handwriting or typing speed, and attention. Recent research with typically functioning college students has found that several of these variables are related to skill in lecture note-taking. They include handwriting speed (Peverly et al., 2007, 2013; Peverly, Garner, & Vekaria, 2014a), language comprehension (Peverly et al., 2013), and sustained attention (Peverly et al. 2014a, b). Similar results have been found with text note-taking (Peverly & Sumowski, 2012). These data suggest that skilled note-taking requires sustained attention as well as the parallel operation of handwriting speed and language comprehension, where greater fluency in the former (a basic skill) and greater skill in the latter (a higher order cognitive skill) are related to better notes.

Sustained attention (SA)

Taking lecture notes requires students to attend to lecture and inhibit distractions (Williams & Eggert, 2002b). Peverly et al. (2014a, b) found that SA and handwriting speed predicted college students' quality of notes. Spinella and Miley (2003) found that college students with higher self-reports of impulsivity had lower grades.

Research has typically examined deficits in sustained attention in adults with visual versions of continuous performance tests where students respond to target stimuli presented on a computer screen. Studies have documented significantly higher omission errors in adults with ADHD compared to controls (Advokat, Martino, Hill, Gouvier, 2007; Hervey, Epstein, & Curry, 2004; Johnson et al., 2001), while others found no differences on omission or commission errors (Holdnack, Moberg, Arnold, Gur, & Gur, 1995; Rapport, VanVoorhis, Tzelepis, & Friedman, 2001). One study that utilized an auditory version of a continuous performance test with 64 non-medicated adults with ADHD and 73 non-ADHD controls found ADHD adults were significantly impaired on omission errors but not commission errors (Seidman, Biederman, Weber, Hatch, & Faraone, 1998). These effects remained even after controlling for psychiatric comorbidity, gender, and age. Thus, it appears that adults with ADHD have deficits in SA. However, limited research exists on attention deficits in postsecondary students.

Verbal working memory (VWM)

VWM is the ability to temporarily store and process verbal information, which is central to performance on a wide range of complex cognitive tasks (Baron, 2004; Buhner, Konig, Pick, & Krumm, 2006; Conway et al., 2005; Engle, 2001), including a variety of academic skills (e.g., Conway et al., 2005). Complex span tasks—which are frequently used to measure VWM—measure both processing and storage.

Despite the prima facie importance of VWM to note-taking, research on undergraduate populations without handicapping conditions has yet to establish a clear relationship between the two. Cohn, Cohn, and Bradley (1995), Hadwin, Kirby, and Woodhouse (1999) and Peverly and colleagues (Peverly et al., 2007, Experiments 1 and 2; Peverly & Sumowski, 2012; Peverly et al., 2013, 2014) did not find a significant relationship between the two, while Bui, Myerson, and Hale (2013), Kiewra and Benton (1988), Kiewra, Benton, and Lewis (1987) and McIntyre (1992) did find a relationship.

Research on adults with ADHD has shown deficits in VWM and short-term memory (Barkley, 2006; Buhner et al., 2006; Gallagher & Blader, 2001; Gropper & Tannock, 2009; Hervey et al., 2004; Holdnack et al., 1995; Johnson et al., 2001; Marchetta, Hurks, Krabbendam, & Jolles, 2008; Murphy et al., 2001; Nigg, 2006; Quinlan & Brown, 2003). Additionally, one study found that VWM predicted multitasking speed in adults with ADHD, providing further support for the role of VWM in complex tasks (Buhner et al., 2006). However, differences in VWM between adults with and without ADHD disappeared once IQ was controlled (Murphy et al., 2001; Rapport et al. 2001), yet remained when controlling for comorbid disorders (Marchetta et al., 2008; Murphy et al., 2001). Thus, there may be an overlap between VWM and IQ.

Handwriting speed (HWS)

HWS, the rate of written word production, is typically measured as the number of letters produced within a specified time limit (Peverly et al., 2007). Research with children and adults indicates that HWS is significantly correlated with essay quality (Connelly, Campbell, MacLean, & Barnes, 2006; Connelly, Dockrell, & Barnett, 2005; Jones & Christensen, 1999; Peverly, 2006). HWS is also significantly related to quality of lecture (Peverly et al., 2007, 2013, 2014a) and text notes (Peverly & Sumowski, 2012) among undergraduates.

Research on the relationship between ADHD and HWS is limited. A meta-analysis of writing skills found the handwriting of students with ADHD in grades one through twelve was significantly poorer than controls (Graham, Fishman, Reed, & Hebert, 2016). Also, poor fine motor output and speed have been observed in clinical populations of children and adults with ADHD (Barkley, 2006; Wolf, 2001).

Listening comprehension (LC)

Comprehension is the ability to understand spoken (LC) or written language (reading comprehension) (Kintsch, 1998). However, findings on the relationship of language comprehension and note-taking are mixed. Kiewra and colleagues (Kiewra & Benton, 1988; Kiewra et al., 1987) did not find a significant relationship between language comprehension and lecture note-taking while Peverly and colleagues did find significant relationships between language comprehension and lecture notes (Peverly et al., 2013) and text notes (Peverly & Sumowski, 2012).

Studies have shown that children and adolescents with ADHD (Aaron, Joshi, Palmer, Smith, & Kirby, 2002; Brock & Knapp, 1996; Ghelani, Sidhu, Jain, & Tannock, 2004; Javorsky, 1996) and incarcerated male adults with ADHD (Samuelsson, Lundberg, & Herkner, 2004) do not show deficits in decoding, word identification, or phonological processing but do show weaknesses in reading comprehension and/or LC (Aaron et al., 2002; Brock & Knapp, 1996; Ghelani et al., 2004; Javorsky, 1996; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003).

Purpose and hypotheses

The purpose of the study was to extend findings from research on lecture note-taking with typically functioning undergraduates (Peverly et al., 2007, 2013, 2014a; Peverly & Sumowski, 2012) to a disabled population–post-secondary students with ADHD. We hypothesized: (1) students with ADHD would have lower means than students without ADHD on measures of SA, VWM, notes' quality and essay performance, (2) SA, HWS, LC and disability status would significantly predict quality of notes; and (3) quality of notes and disability status would significantly predict written recall.

Method

Participants

Participants were undergraduate and graduate students ($n = 72$) from multiple universities in the northeastern United States. They were recruited from offices of disability services, counseling centers, university courses, department emails, referrals, and posted fliers. The mean age of the sample was 22.62 years ($SD = 3.68$; median = 21.41; range = 18.26–36.61 years). Sixty-eight percent ($n = 49$) were female and 11.1% ($n = 8$) were nonnative English speakers. Reported race/ethnicity was: White American (55.6%), Asian American/Pacific Islander (16.7%), Black/African–American (6.9%), Latino/a (2.8%), Non-US Citizen (1.4%), Other (2.8%), and two or more groups (12.5%). Most were undergraduates ($n = 49$; 68.1%). Less than half identified as psychology majors (41.7%). Everyone received $20 to complete the study. Those who referred another student to the study received an additional five dollars.

ADHD self-report group

Since participants were not evaluated to confirm ADHD diagnosis, they are non-clinic referred individuals with self-reported diagnoses of ADHD (hereafter referred to as the ADHD group). The ADHD group was 30.6% of the sample ($n = 22$), which consisted of 50% females and 72.7% undergraduates (age: $M = 23.63$; $SD = 4.17$). Sixty-four percent were registered with their school's office of disability services (68.2% took medication). According to each university's disability services' website, all registrants had to file appropriate documentation including: a comprehensive evaluation conducted within the past 3 years using reliable and valid standardized measures and completed by a qualified evaluator, a specific diagnosis of ADHD using *DSM-IV* criteria, evidence of a substantial limitation to academic functioning, and a list of recommended accommodations. However, since recruitment was expanded beyond offices of disability services to obtain an adequate sample size, 36% of the sample was not registered at an office of disability services. A one-way MANOVA compared the two groups (i.e., registered and not registered) on all independent and dependent variables. The assumption of equal covariance matrices was met. The multivariate test was not significant [Wilks' $\lambda = .82$, $F(6,15) = .55$, $p = .766$, observed power = .16].

As a further check of self-reported ADHD symptoms, the *Conners' Adult ADHD Rating Scale-Short Self-Report Form* (Conners, Erhardt, & Sparrow, 1999; *CAARS-S: S*) was administered to each participant. Table 1 reports means, standard deviations, and ranges for participants in the ADHD group (nine were in the clinical range; > 65). A one-way MANOVA compared those registered or not registered at offices of disability services on the five scales of the *CAARS*. The assumption of equal covariance matrices was met. The multivariate test was not significant [Wilks'

Table 1 Means, standard deviations, and ranges for the CAARS within the ADHD group (n = 22)

Scale	Mean	SD	Minimum	Maximum
Inattention/memory problems	65.82	11.66	44	83
Hyperactivity/restlessness	60.82	11.34	41	78
Impulsivity/emotional lability	54.95	11.46	40	80
Problems with self-concept	60.77	9.90	40	76
ADHD index	63.32	11.75	47	90

Reported scores are *T*-scores with a mean of 50 (*SD* = 10). *T*-scores greater than or equal to 66 are considered elevated

λ = .71, $F(6,15) = 1.29$, $p = .318$, observed power = .34]. A discriminant function analysis using T-scores from the subscales of the CAARS was used to test if the CAARS reliably discriminated between the ADHD and non-ADHD groups, which it did (86.4% correct classification rate). See Supplemental Analyses.

Non-ADHD group

The control group, which made up 69.4% of the ample ($n = 50$), consisted of 76% females, and 66% were undergraduates with a mean age of 22.18 years ($SD = 3.40$). Four students within the control group reported a prior but not current diagnosis of ADHD. None of them endorsed clinically elevated symptoms on the *CAARS*. See Supplemental Analyses for other comparisons between the ADHD and non-ADHD groups.

Materials

All measures were group administered. Inter-rater agreement in scoring (agreement/agreement + disagreement) was used to establish reliability for total scores on all measures across 30 randomly chosen protocols and ratings from three independent graduate student raters. Inter-rater reliability for the lecture notes and the written summary were calculated by adding the number of item agreements between two independent raters over the total number of items (i.e., 15) and then taking the average of these scores across 30 randomly chosen protocols. Disagreements were settled by consensus.

Conners' Adult ADHD Rating Scale

The *Conners' Adult ADHD Rating Scale-Short Self-Report* (Conners et al., 1999; *CAARS-S: S*), a commonly used rating scale (Reilley, 2005) was used to assess participants' reports of symptoms associated with ADHD and related impairments. Items concerning behaviors or problems experienced by adults were presented as statements and participants were asked to rate how much or how frequently each item best described them by circling the appropriate number on a four-point Likert scale of 0–3. Inter-rater agreement was 1.0. For further information on the CAARS-S, see Supplemental Materials.

Lecture

The lecture and the scoring method used to score participants' lecture notes were taken from Brobst (1996). The videotaped lecture, read from a prepared text by the second author at a rate of 2.04 words per second, was approximately 23 min long and summarized basic concepts and research in the psychology of problem solving. The content of the lecture was adapted from a chapter by Voss (1989) titled "Problem Solving and the Educational Process," from a book designed for use in an undergraduate course in educational psychology (Brobst, 1996). The lecture consisted of six general themes and 15 content areas. Participants were given three sheets of blank paper and told to take notes. They were also told they would be allowed 10 min to study their notes in preparation for written recall later in the study. Participants' notes were scored for quality. Overall quality scores could range from 0 to 45. Inter-rater reliability was .87. For further information on scoring, see Supplemental Materials.

Written recall (WR)

Participants were instructed to write an organized summary of the lecture without notes. They were allowed 15 min and given two sheets of paper for the task. The same method and criteria used for scoring the notes was used to score recall (e.g., participants' quality scores could range from 0 to 45). Inter-rater reliability was .96.

Sustained attention (SA)

The Lottery subtest of the *Test of Everyday Attention* (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994; *TEA*) was used to measure SA. In this task, participants are told to listen for their winning number, which ends in the number "55" (Version A), and then to write down the preceding two letters. To do this, participants listen to a 10-min series of numbers of the form "BC143, LD967" presented on a compact disc. They were required to write down 10 sets of letters. Inter-rater agreement ranged from .94 to .96 among three independent raters. See Supplemental Materials for more information on the TEA.

Verbal working memory (VWM)

The listening span test is based on one used by Daneman and Carpenter (1980) to measure participants' auditory verbal VWM. Participants were presented with 60 unrelated sentences divided into five groups of three sets of sentences each via compact disc. The first group consisted of three sets of two sentences each. The next group consisted of three sets of three sentences each, and so on until the last group, which consisted of three sets of six sentences each. Participants listened to each sentence in a set, indicated whether each sentence made sense or not ('yes'; 'no') and then recalled the last word of each sentence. Inter-rater agreement ranged from .94 to .96 for the processing scores and .84 to .94 for the total scores. Six participants were eliminated from the original sample because they were not sufficiently engaged with the task, which reduced the sample to 72. For more details on administration and scoring see Supplemental Materials.

HWS

The alphabet task, which was used to measure HWS, is based on one used by Berninger, Mizokawa, and Bragg (1991). Participants were required to write the alphabet horizontally in capital or lowercase letters, starting with the letter "A," repeatedly for 1 min. One point was awarded for each recognizable letter. Inter-rater agreement was 1.0.

LC

The Listening Comprehension subtest of the *Kaufman Test of Educational Achievement-Second Edition* (Kaufman & Kaufman, 2004; KTEA-II) was used as a measure of participants' listening comprehension. The test consists of 6 passages and each passage is followed by two to four questions. Questions are short-answer and multiple-choice questions, which measure either literal or inferential comprehension. The KTEA-II is administered individually but was modified for group administration. It was scored based on guidelines provided in the *KTEA-II* manual. Participants could earn 19 points. Raw scores were used in analyses since standard administration was not utilized. Inter-rater agreement among three independent raters ranged from .82 to .84. See Supplemental Materials for more information.

Procedure

Participants received a packet of materials with a consent form outlining the study's purpose, procedures and materials, time needed to complete the study, and participants' rights. If participants agreed to participate, they signed the consent form, completed a short demographics questionnaire, and filled out the *CAARS-S:S* (15 min). Subsequently, participants watched the lecture and took notes (23 min), completed measures of SA (10 min), VWM (15 min), and HWS (1 min). Participants then reviewed their notes for 10 min before completing the listening comprehension measure (17 min). Finally, participants wrote a summary of the lecture (15 min). Over the course of the experiment, participants were offered snacks and given a break during the review period.

Results

Table 2 contains the means, standard deviations, range of scores for the total sample, and the distribution for all variables. The variables HWS, VWM, notes' quality, and written recall met all assumptions of normality. The measures of SA and LC were slightly negatively skewed and there was evidence for positive

Table 2 Means, standard deviations, ranges, skew, and kurtosis for predictor and outcome variables

	Mean	SD	Range	Skew	Kurtosis
Attention	8.76	1.11	5.0–10.0	− 1.40 (.28)	2.24 (.56)
Handwriting speed	118.92	23.24	71–176	.13 (.28)	− .63 (.56)
VWM	9.13	2.79	4–15	.14 (.28)	− .55 (.56)
Listening comp.	14.15	2.77	4–19	− 1.22 (.28)	2.21 (56)
Notes	22.13	6.44	8–36	.01 (.28)	− .27 (.56)
Written recall	7.53	3.85	0–18	.41 (28)	− .13 (.56)

VWM verbal working memory, *Listening Comp.* listening comprehension kurtosis, indicating few participants' scores fell in the very low and very high ranges. Since the variables were only slightly skewed, no transformations were performed. See Tables 3, 4 and 5 for the correlations between the IVs and the DVs (total, and divided by group). See Supplemental Materials for a power analysis.

Mutlivariate and univariate tests

A MANOVA compared the ADHD (n = 22) and non-ADHD (n = 50) groups on all independent (IV) and dependent variables (DV) to evaluate Hypothesis 1. The assumption of equal covariance matrices was met [Box's $M = 29.35$, $F(21, 6453) = 1.23$, $p = .210$]. The multivariate test was significant [Wilks' $\lambda = .70$, $F(6, 65) = 4.73$, $p < .001$, partial $\eta^2 = .30$, observed power = .98]. ANOVAs (a Bonferroni correction; $p \leq .008$) revealed the non-ADHD group had significantly higher HWS [$F(1, 70) = 12.52$, $p = .001$, partial $\eta^2 = .15$] and written recall than the ADHD group [$F(1, 70) = 9.89$, $p = .002$, partial $\eta^2 = .12$]. See Table 6. Although there were no other significant differences, the means of the groups did significantly differ on SA at $p = .012$. Hypothesis 1 was generally not confirmed. Students with ADHD did not have significantly lower scores on measures of SA, VWM, and notes' quality. They had lower scores on essay performance, as hypothesized, and HWS.

Multiple regression analyses

Quality of notes was regressed on all of the IVs. The model was significant (tolerance and variance inflation factor values were within acceptable limits; $R = .45$, $R^2 = .20$, $R^2_{\text{adjusted}} = .14$; $F(5, 66) = 35.73$, $p = .01$). The effect size (R^2) was moderate (Cohen, 1992). Hypothesis 2 was largely confirmed. SA ($\beta = .25$, $p < .05$) and LC ($\beta = .29$, $p < .05$) but not HWS were the only significant predictors. See Table 7.

Table 3 Results of univariate ANOVAs comparing ADHD and non-ADHD groups across all measures (n = 72)

Source	ADHD group (n = 22)		Non-ADHD group (n = 50)		Significance
	Mean	SD	Mean	SD	
Attention	8.27	1.35	8.98	.93	.012
Handwriting speed	105.36	25.38	124.88	19.69	.001**
VWM	8.64	2.42	9.34	2.94	.328
Listening comp.	14.23	3.37	14.12	2.50	.881
Notes	21.82	5.58	22.26	6.83	.791
Written recall	5.50	3.35	8.42	3.74	.002*

VWM verbal working memory; *Listening comp.* listening comprehension; Bonferroni correction = .008
*$p \leq .008$; **$p = .001$

Table 4 Intercorrelations among the independent and dependent variables for entire sample (n = 72)

Variable	1	2	3	4	5	6	7
1. Disability status	–						
2. Attention	− .30*	–					
3. Handwriting speed	− .39**	.29*	–				
4. VWM	− .12	.11	.02	–			
5. Listening comp.	.02	− .01	.02	.21	–		
6. Notes	− .03	.26*	.24*	− .10	.25*	–	
7. Written recall	− .35**	.23	.36**	.17	.36**	.59**	–

VWM verbal working memory, *Listening comp.* listening comprehension

*p < .05; **p < .01; ***p < .001

Table 5 Intercorrelations among the independent and dependent variables for the ADHD group (n = 22)

Variable	1	2	3	4	5	6
1. Attention	–					
2. Handwriting speed	.25	–				
3. VWM	.19	.00	–			
4. Listening comp.	.05	− .05	.13	–		
5. Notes	.28	.53*	− .28	.39	–	
6. Written recall	.18	.45*	.00	.32	.46*	–

VWM verbal working memory, *Listening comp.* listening comprehension

*p < .05; **p < .01; ***p < .001

Table 6 Intercorrelations among the independent and dependent variables for the non-ADHD group (n = 50)

Variable	1	2	3	4	5	6
1. Attention	–					
2. Handwriting speed	.16	–				
3. VWM	.02	− .04	–			
4. Listening comp.	− .06	.08	.26	–		
5. Notes	.27	.12	− .05	.19	–	
6. Written recall	.11	.17	.18	.43**	.68**	–

VWM verbal working memory; *Listening comp.* listening comprehension

*p < .05; **p < .01; ***p < .001

Table 7 Summary of regression analysis predicting quality of notes (n = 72)

Variable	B	SE B	β	Tolerance	VIF
Disability status	1.33	1.71	.10	.80	1.25
Attention	1.47	.68	.25*	.87	1.15
Handwriting speed	.06	.03	.20	.81	1.23
VWM	− .40	.26	− .18	.94	1.07
Listening comp.	.66	.26	.29*	.95	1.05

VWM verbal working memory, *Listening comp.* listening comprehension, *VIF* variance inflation factor

*$p < .05$; **$p < .01$; ***$p < .001$

Written recall was regressed on IVs and quality of notes. The model was significant (tolerance and variance inflation factor values were within acceptable limits; $R = .74$, $R^2 = .55$, $R^2_{\text{adjusted}} = .51$; $F(6, 65) = 13.06$, $p < .001$. The effect size (R^2) was large (Cohen, 1992). The third hypothesis was largely confirmed. Notes' quality (β = .53, $p < .001$), disability status (β = -.29, $p < .01$) and LC (β = .19, $p < .05$) were significant predictors. See Table 8.

Interactions between group (ADHD or non-ADHD) and each continuous independent and dependent variable were examined in individual regression analyses due to the small sample. All continuous variables were centered. There were no significant interactions. See Supplementary Materials for additional post hoc analyses comparing differences between students from different schools and undergraduate and graduate students.

Discussion

Students with ADHD performed worse than their non-handicapped counterparts on written recall and handwriting speed. There were no reliable differences between groups on note-taking, sustained attention, listening comprehension, and working

Table 8 Summary of regression analysis predicting written recall (n = 72)

Variable	B	SE B	β	Tolerance	VIF
Disability status	− 2.36	.78	− .29**	.80	1.26
Attention	− .17	.32	− .05	.81	1.23
Handwriting speed	.02	.02	.13	.78	1.28
VWM	.21	.12	.15	.90	1.11
Listening comp.	.27	.13	.19*	.87	1.15
Notes	.32	.06	.53***	.80	1.25

VWM verbal working memory, *Listening comp.* listening comprehension, *VIF* variance inflation factor

*$p < .05$; **$p < .01$; ***$p < .001$

memory. The regression analyses indicated that sustained attention and listening comprehension were significantly related to quality of notes and disability status, notes, and listening comprehension were significantly related to written recall. We review the findings for note-taking first, followed by recall.

Note-taking

Disability status

There were no significant differences between groups on quality of notes and disability status was not a significant predictor of quality of notes, which suggests that note-taking did not play a role in group differences in recall. Accommodations provided to many students with ADHD include copies or audio-recordings of lecture notes. While previous research has not measured quality of lecture notes between postsecondary students with and without ADHD, if our results are replicated, they may suggest that college students with ADHD be given accommodations for studying notes and testing taking but not note-taking. We discuss these issues in more detail below.

SA

There were no differences in SA between groups which is contrary to other research which has found deficits in vigilance or SA in adults (Hervey et al., 2004; Johnson et al., 2001; Murphy et al., 2001; Seidman et al., 1998) and postsecondary students with ADHD (Weyandt & DuPaul, 2006). However, two studies also found no differences in attention between confirmed ADHD adults and controls (Holdnack et al., 1995; Rapport et al., 2001). Furthermore, there is some support for the idea that ADHD is not primarily a disorder of attention but a disorder of behavioral inhibition (Barkley, 2006) or executive functions (Cutting & Denckla, 2003).

There are several possible explanations for the lack of significance between groups in SA: (a) participants reported symptoms of ADHD that did not always meet the threshold for the disorder and/or were not experiencing impaired educational functioning; (b) students with ADHD in postsecondary institutions may not exhibit some or the same level of cognitive deficits as those in the general ADHD adult population due to higher IQs or better compensatory strategies, and/or (c) 68% of the ADHD sample reported taking medication to focus. Regarding explanation “b” significant similarities between college students with confirmed and self-reported symptoms of ADHD were found between groups and between both groups and controls (Richards, Rosen, & Ramirez, 1999). Also, a review of the literature suggests that postsecondary students with both confirmed and self-reported ADHD symptoms generally obtain lower GPAs, receive more special education services, are more likely to be on academic probation, and are less likely to graduate when compared to controls (Barkley, 2006; Barkley et al., 2008; Blaise et al., 2009; DuPaul et al., 2009; Heiligenstein et al., 1999; Kaminski et al., 2006; Lewandowski et al., 2008; Murphy et al., 2002; Norwalk et al., 2009; Weyandt & DuPaul, 2006; Wolf, 2001).

Regarding medication (explanation ‘c’) adolescents with ADHD have shown an increase in note-taking due to the effect of methylphenidate (Evans et al., 2001), and stimulant medication has been shown to improve SA in adults with ADHD (Advokat, 2010). However, a review of research on adults with ADHD found that stimulant medications do not equalize academic achievement or improve performance on more complex cognitive tasks (Advokat, 2010).

Although there were no significant differences between groups in SA, SA was significantly related to notes’ quality, which confirms Peverly et al. (2014a, b), who used the same measure of SA with typically functioning undergraduates. These findings make logical sense. Students must listen, inhibit distractions, and maintain attention during lecture.

LC

ADHD status was not significantly related to LC, a construct that has not been examined previously in the ADHD literature. Research on reading comprehension, which correlates with LC, has found lower reading comprehension in children (Brock & Knapp, 1996; Ghelani et al., 2004; Javorsky, 1996) and incarcerated adults with ADHD (Samuelsson et al., 2004) compared to controls. Ghelani et al. (2004) noted though that the scores of students with ADHD were in the average range. In general, research on differences in reading comprehension among children and adults with ADHD and controls has produced inconsistent results.

The significant relationship between LC and note-taking is consistent with previous research on the relationship between LC and quality of notes presumably because of the high correlation (.90) between listening and reading comprehension at the college level (Gernsbacher, Varner, & Faust; 1990; Peverly & Sumowski, 2012; Peverly et al., 2013).

HWS

Students with ADHD had significantly lower scores on HWS than controls. Although we are not aware of research on the relationship of adults with ADHD and HWS, research has documented problems with handwriting (Graham et al., 2016) and slow motor output in children with ADHD (Barkley, 2006; Cutting & Denckla, 2003), and composition writing in adults with ADHD (Gregg, Coleman, Stennett, & Davis, 2002; Wolf, 2002).

In contrast to previous research, HWS was not a significant predictor of quality of notes (Peverly et al., 2007, 2013, 2014a; Peverly & Sumowski, 2012). However, HWS did significantly correlate with quality of notes (.26). A possible explanation for this discrepancy is insufficient statistical power because of the sample size.

VWM

There were no differences between the ADHD and non-ADHD groups on VWM. This finding is contrary to studies documenting mild to significant deficits in verbal VWM and short-term memory in adults with ADHD (Barkley, 2006; Buhner et al., 2006; Gallagher & Blader, 2001; Gropper & Tannock, 2009; Hervey et al., 2004; Holdnack et al., 1995; Johnson et al., 2001; Marchetta et al., 2008; Nigg, 2006; Quinlan & Brown, 2003).

Also, VWM did not significantly predict notes. The association of VWM to note-taking has been equivocal. Some found that VWM was related to notes' quality using a complex span task (Bui et al., 2013; Piolat, 2007) and others have not (Cohn et al., 1995; Peverly et al., 2007, 2013, 2014a; Peverly & Sumowski, 2012).

Given the resource demanding nature of lecture note-taking, the equivocal relationship of VWM to note-taking is perplexing. One possible reason is the exclusive focus on the verbal components of WM in note-taking research. Since note-taking is a form of writing (Peverly et al., 2013) and Kellogg (1999) has argued that writing relies on the verbal, visual and spatial components of WM, note-taking researchers may not always be using appropriate measures of WM. Indeed, research suggests that different writing processes burden different working memory systems: phonological loop (e.g., translating thoughts into words), visual (e.g., planning that involves visualization), and spatial (e.g., organizing text) (Galbraith, Hallam, Olive, & Le Bigot, 2009; Kellogg, Olive & Piolat, 2007; Olive, Kellogg & Piolat, 2008). Based on these data, future research on note-taking should include measures of visual and spatial working memory.

Written recall

Disability status

Students in the ADHD group recalled 12.2% of the ideas from lecture compared to 18.7% in the comparison group. This finding is consistent with research on children, adolescents and young adults with ADHD, which includes poor performance on tests and poor writing (Wolraich et al., 2005; Graham et al., 2016) especially under timed conditions (Gregg et al., 2002). However, time did not seem to play a factor on written recall in this study since the majority of students finished prior to the time limit.

There are three possible reasons for our results: (a) our coding of notes may not have been sensitive enough to detect group differences in note-taking, (b) students with ADHD may be less adept at reviewing notes, which we did not measure, and/or (c) students with ADHD may be less adept at recalling information from long term memory after review. We do not have a body of research on the note-taking skills of students with ADHD to evaluate 'a'. However, research related to 'b' and 'c' has documented that students with ADHD have poor study skills which are related to poor encoding (Allsopp et al., 2005; Crede & Kuncel, 2008; Kaminski et al., 2006; Norwalk et al., 2009; Reaser et al., 2007) and difficulties with recall (Holdnack et al., 1995; Johnson et al., 2001; Roth et al., 2004; Seidman et al., 1998). For example, several studies have found that adults with ADHD have difficulty with the California verbal learning test, which requires participants to learn a list of 16 nouns from four semantic categories that are presented repeatedly over five trials. Recall is required after each trial. Adults with ADHD recall fewer items and use the strategy of clustering to facilitate recall less than controls (Holdnack et al., 1995; Roth et al., 2004; Seidman et al., 1998). Thus, future research on note-taking with students diagnosed with ADHD should focus on the strategies associated with taking notes, which is the first stage of encoding, and the strategies associated with review, which is the second and more elaborative and integrative level of encoding. Conceptualized in this way, it is not surprising that the effect size for the second encoding stage is three times that of the first (Kobayashi, 2005, 2006).

Another possible cause of the ADHD group's relatively poor performance on written recall in this experiment is writing skills. In a meta-analysis Graham et al. (2016) found that the written products produced by students with ADHD in grades one through twelve, in comparison to controls, were significantly shorter and poorer in quality. Students with ADHD also had poorer vocabulary, spelling, and handwriting (fluency and legibility) than controls. It may be that some of the students with ADHD who are admitted to college have deficits in writing skills.

Quality of notes

Although there were no significant differences between groups on quality of notes, it was the best predictor of recall, which confirms other findings with typically functioning college students (Peverly et al., 2007, 2013, 2014a, b; Reddington, Peverly, & Block, 2015). These findings are also consistent with research on the relationship between note-taking and test performance, regardless of test type (Kiewra & Benton, 1988; Kiewra et al., 1991; Norton & Hartley, 1986; Peverly et al., 2007; Titsworth & Kiewra, 2004; Williams & Eggert, 2002a). The strength of the relationship between notes and written recall may simply be due to the opportunity students have to access and write down the macrostructure of the lecture they encoded during note-taking and review. Research suggests students are more likely to recall information recorded in their notes than information that was not recorded (Kiewra et al., 1987).

LC, HWS, SA and VWM

LC also significantly predicted written recall. Since LC and the measures of reading comprehension used in other note-taking research are proxies for verbal ability (Gernsbacher et al., 1990), these results replicate previous findings on the importance of language comprehension to typically functioning undergraduates in text (Peverly & Sumowski, 2012) lecture note-taking (Peverly et al., 2013). These findings suggest that language comprehension enables construction of a qualitatively better representation of lecture or text in long term memory (Kintsch, 1998).

HWS did not significantly predict written recall. This finding replicates previous research (Peverly et al., 2007, 2013, 2014a, b; Peverly & Sumowski, 2012; however, see Reddington et al., 2015).

Finally, SA and VWM did not significantly predict written recall, which is consistent with previous research (Peverly et al., 2007, 2013, 2014a, b; Peverly & Sumowski, 2012).

Implications for practice and future research

Our findings have implications for educational practice. While common accommodations in postsecondary settings include providing students with a copy of lecture notes or granting them permission to audiotape lectures, our findings if replicated, indicate they may not be warranted. Students with ADHD who gain admission to postsecondary institutions may have established compensatory strategies for note-taking. And given the potential advantages of note-taking, including increased engagement (Carrier & Titus, 1979; Mueller & Oppenheimer, 2014) and more generative learning (Stefanou, Hoffman & Vielee, 2008), students may greatly benefit from engaging in lecture note-taking.

Students with ADHD differed significantly from their non-ADHD peers on written recall. Based on our findings and the findings of others (Holdnack et al., 1995; Roth et al., 2004; Seidman et al., 1998), research should replicate the problem, and if it is found, focus on locus of the problem– relatively poor strategies for encoding and reviewing notes and/or problems with strategies for retrieval of information from long term memory. If research verifies some or all of these problems, attention should be shifted to instructing students with ADHD on strategies to mitigate their weaknesses rather than relying on extra time, which may not produce the intended results (Lovett & Leja, 2015).

Our finding that students with ADHD have slower HWS has implications for writing skill. Students must be fluent in basic lower level processes such as HWS, to free up resources for the higher level processes of generating, organizing and editing ideas when writing essays (Berninger & Swanson, 1994; McCutchen, 2000). If students with ADHD have difficulties with HWS, they may have fewer resources to devote to the higher level processes necessary for writing (Graham et al., 2016) and taking notes even though we did not find group differences in note-taking. If this is verified in future research, the accommodation of providing students with a laptop for essay exams and other related activities may be warranted.

Limitations

There are several limitations. First, because of the small sample we may have underestimated differences between students with and without ADHD due to low statistical power. Also due to the difficulties recruiting a sufficient sample of ADHD postsecondary students, the current sample is not homogeneous. Differences among students with and without ADHD may exist across academic settings, higher education level (undergraduate versus graduate), and gender.

Also, our study included students who self-reported diagnoses and symptoms of ADHD. Therefore, caution should be used when generalizing our results to postsecondary students with confirmed diagnoses. In addition, the current study did not assess other psychiatric disorders and the potential impact of comorbidity on lecture note-taking, test-taking or the independent variables. Further, we did not evaluate the impact of the review of notes on written recall nor did we record the time students spent writing what they could remember to determine whether one group finished more quickly than the other. Finally, as discussed previously, the impact of psycho-stimulant medications cannot be ruled out.

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