

The Relationship of Handwriting Speed, Working Memory, Language Comprehension and Outlines to Lecture Note-taking and Test-taking among College Students

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Summary: A previous investigation of the cognitive processes underlying note-taking found that handwriting speed was the only significant predictor of notes, and notes were the only significant predictor of test performance. This investigation sought to extend these results by evaluating the effects of handwriting speed, language comprehension, two measures of working memory (complex span and executive attention) and an outline on note-taking and test performance (written summary). Participants were randomly assigned to an outline or not no-outline group (Group) to determine the effect of an outline on handwriting speed. Results from a path analysis indicated that handwriting speed, language comprehension and Group were significantly related to notes. The relationship between the independent variables and the written summary was not completely mediated by notes as in the previous investigation. Notes, Group and language comprehension were related to the written summary. The implications of the findings are discussed. Copyright © 2012 John Wiley & Sons, Ltd.

After approximately three decades of research (Berninger & Richards, 2012), there seems to be a consensus about the cognitive processes related to writing essays. Theory and research suggests that writers must be fluent in (i) generating ideas and (ii) transcribing them quickly before they are forgotten (Berninger & Swanson, 1994; Berninger et al., 1992; McCutchen, 2000; McCutchen, Covill, Hoyne, & Mildes, 1994; Olive & Kellogg, 2002; Olive, Alves, & Castro, 2009; Peverly, 2006; Ransdell & Levy, 1996). Efficiency in executing (i) and (ii) significantly lessens the strain on working memory, which in turn enables writers to more efficiently access and use the metacognitive (Bereiter & Scardamalia, 1982, 1987; Flower & Hayes, 1980; Hayes, 1996) and other cognitive resources (e.g., language comprehension, genre and content knowledge; McCutchen, 2000) needed to create high quality reader-based prose.

Lecture note-taking

Although we have learned a great deal about the cognitive processes related to writing essays, we know very little about one important writing skill, lecture notes, cryptic written records of important information presented in lecture. Most college students rate lecture note-taking as an important educational activity (Dunkel & Davy, 1989), and almost all students take notes in classes (approximately 98%; Palmartier & Bennett, 1974). In addition, research has shown that recording and reviewing notes from classes is related to test performance (Bretzing & Kulhavy, 1981; Fisher & Harris, 1973; Kiewra et al., 1991; Kiewra & Fletcher, 1984; Peverly, Brobst, Graham, & Shaw, 2003; Rickards & Friedman, 1978; Titsworth & Kiewra, 2004). Research on the cognitive processes related

to effective note-taking could inform the instruction of note-taking skills (Peverly, Marcelin, & Kern, in press).

There are some noticeable differences between lecture note-taking and essay writing. For instance, note-taking is a relatively passive activity predicated in information selected from the stream of ideas presented by a lecturer rather than the self-generated text that characterizes essays. Additionally, lecture notes are noticeably less coherent and cohesive than well-written essays because notes are a personal memory aid and not written for an audience. Nonetheless, with the exception of metacognitive processes, cognitive task analyses of note-taking suggest that the cognitive constructs that underlie note-taking are similar to those that underlie writing, specifically transcription fluency (in the essay writing literature, transcription fluency consists of two components: handwriting speed and spelling), working memory and language comprehension, among others (Kiewra, Benton, & Lewis, 1987; Kobayashi, 2005; Peverly, 2006; Peverly et al., 2007; Piolat, Olive, & Kellogg, 2005). That is, note-takers must (i) interpret and select the most important ideas, (ii) hold the information in working memory and (iii) write them down quickly before they are forgotten (Peverly et al., 2007; Piolat et al., 2005). Efficiency in executing (iii), a basic skill, should lessen the strain on working memory, which in turn should enable note-takers to more efficiently use higher level processes to interpret the lecture.

The relationships between note-taking skill and some of the variables in the aforementioned cognitive task analyses of note-taking were assessed in two investigations by Peverly et al. (2007). Specifically, they evaluated the contributions of verbal working memory, the ability to identify main ideas (a proxy of language comprehension), handwriting speed, spelling skill and verbal fluency (e.g., how many examples of the semantic category 'furniture' can be generated in a minute) to note-taking, and all of these plus notes' quality, to test

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performance. Handwriting speed was the only significant and positive predictor of notes' quality, and notes' quality was the only significant predictor of written recall in both investigations. Thus, notes completely mediated the relationship between handwriting speed and test performance.

The purposes of the present study were to (i) replicate the relationship of handwriting speed to notes and determine whether a skeletal outline of the lecture might abrogate that relationship and (ii) determine if language comprehension and working memory are also significantly related to the notes and to the written summary.

Handwriting speed

The importance of handwriting speed to notes found by Peverly *et al.* (2007) parallels the importance of that construct to essay writing found in correlational and experimental research with elementary and middle school students (Berninger *et al.*, 1997; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Graham, Harris, & Fink, 2000; Jones, 2004; Jones & Christensen, 1999), and correlational and experimental research with adults (Brown, McDonald, Brown, & Carr, 1988; Connelly, Campbell, MacLean, & Barnes, 2006; Connelly, Dockrell, & Barnett, 2005; Olive & Kellogg, 2002). We sought to replicate the finding by Peverly *et al.* that handwriting speed significantly predicts notes' quality. We did not measure spelling because Peverly *et al.* (2007) evaluated the relationship of handwriting speed, compositional fluency (as measured by the Writing Fluency subset of the Woodcock–Johnson) and spelling to notes. All three correlated significantly with notes but only handwriting speed was a significant predictor of notes.

We also examined the relationship of handwriting speed to notes' quality for different note-taking formats, that is, with and without a skeletal outline of the lecture. Skeletal outlines, which provide students with the lecture's main ideas, with spaces between them for taking notes on information related to the main ideas, are frequently used in classrooms to support students' note-taking. Students given this type of outline before lectures generally record more notes and do better on tests than those without an outline (Armbruster, 2009; Kiewra, 1991). Outlines may reduce students' cognitive burden during lectures by making the thematic structure of the lecture more apparent (Lorch, Lorch, & Matthews, 1985). Without an outline, students may need to spend more time determining the lecture's important points, with correspondingly less time for recording information before the next important point is presented. Thus, students with slower handwriting speed may be at a disadvantage in lectures without outlines. In this study, students were randomly assigned to an outline group (students were given a printed outline beforehand, with headings and subheadings) or a no-outline group.

Influence of other cognitive factors on note-taking

We investigated two variables that cognitive task analyses of lecture note-taking suggest are among the higher order cognitive constructs needed to take high quality lecture notes: language comprehension and working memory (Kobayashi, 2005; Peverly, 2006; Piolat *et al.*, 2005).

Language comprehension

Language comprehension is the understanding of spoken or written words (Kintsch, 1998), which is based in an understanding of semantics (vocabulary) and grammar (syntax and morphology), and in reading, the ability to recognize words. Logically, language comprehension should be a strong predictor of skill in lecture note-taking. At some level, students must be able to use language to comprehend a lecture and determine its main points before writing them down (Kiewra & Benton, 1988; Kiewra *et al.*, 1987; Kobayashi, 2005; Peverly, 2006; Piolat *et al.*, 2005). Although research on the relationship between language comprehension and note-taking is extremely limited, research has not confirmed an association between the two. The main idea of identification task used in Peverly *et al.* (2007) did not correlate with any of the other independent variables and was not related to either of the dependent variables: quality of notes or test performance. Also, Kiewra and colleagues (Kiewra *et al.*, 1987; Kiewra & Benton, 1988) failed to find a relationship between lecture notes and performance on the English and Comprehension subtests of the American College Test (ACT).

It is not clear why research has not found a relationship between language comprehension and notes. Although Peverly *et al.* (2007) cited methodological flaws with the main idea task and/or participant fatigue as explanations, the ACT focuses on the comprehension of written texts, and reading comprehension correlates strongly with listening comprehension among college adults (approximately .8 to .9; Gernsbacher, Varner, & Faust, 1990). Also, language comprehension accounted for all of the variance of reading comprehension among eighth-grade students (Adlof, Catts, & Little, 2006). Considered collectively, these findings suggest that reading comprehension is a strong proxy for language comprehension in these populations (Adlof, Perfetti, & Catts, 2011; Perfetti, 1986). Further, measures of listening comprehension provided the same level of predictive power of lecture note-taking among high school (Gleason, 2012) and college students (Vekaria, 2011) as reading comprehension did in an investigation of text note-taking among college students (Peverly & Sumowski, 2011). Thus, to investigate the relationship between language comprehension and note-taking, we used the *Nelson–Denny Reading Test* (Nelson–Denny), a well standardized measure of reading skill for college students. Also, we shortened the recommended administration time of the Nelson–Denny to increase variation in performance (see the Method section for more information). Relatedly, Peverly and Sumowski (2011) used the Nelson–Denny (with shortened administration time) in their investigation.

Working memory

Working memory is a cognitive workspace where information from the environment and long-term memory is held, manipulated and interpreted, to achieve goals such as remembering and learning (Baddeley, 2000). Because lecture note-taking is cognitively challenging because of the fleeting presence of auditory verbal stimuli, and the need to keep large amounts of verbal information active in working memory for the purposes of interpretation and transcription (Piolat *et al.*, 2005), individual differences in verbal working memory (VWM) may be related to individual differences in lecture

note-taking. Also, VWM has been found to be significantly related to individual differences in reading (Baddeley, 2000; Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992), writing (Kellogg, 2001; Swanson & Berninger, 1996) and mathematics (Swanson & Kim, 2007). Thus, VWM should correlate with note-taking, given the importance of VWM to other academic skills.

Regardless, research on the relationship between working memory and lecture note-taking has been mixed. Some studies found a significant positive relationship between VWM and note quality (Kiewra et al., 1987; Kiewra & Benton, 1988; McIntyre, 1992), and others did not (Cohn, Cohn, & Bradley, 1995; Hadwin, Kirby, & Woodhouse, 1999; Peverly et al., 2007).

The inconsistency may be due to differences in the measures used to measure VWM. Kiewra and colleagues (Kiewra & Benton, 1988; Kiewra et al., 1987) and McIntyre (1992) had participants unscramble randomly ordered words to make a sentence (six sentences in total) or arrange randomly ordered sentences to make a coherent paragraph. The materials were always in full view. These tasks are different than the span tests, which require both storage and processing, typically used to assess working memory. One commonly used complex span task is Daneman and Carpenter's (1980) reading span test that requires participants to read a set of unrelated sentences (two to six) one at a time. After reading each sentence, the sentence is removed from view, and participants say whether the sentence makes sense or not (processing). The procedure is repeated for the remaining sentences in the set. At the end of the set, participants are asked to remember the last word of each sentence (storage). Because the tasks used by Kiewra and colleagues do not require participants to store and process information in the same way as complex span tasks, they may not adequately measure span or processing. Because the research referred to previously on the significant relationship between working memory and achievement often used complex span tasks, we used Daneman and Carpenter's (1980) listening span task, which has been used extensively in working memory research with adults and children.

Another possible reason for the lack of a significant relationship between VWM and note-taking in studies by Cohn et al. (1995), Hadwin et al. (1999) and Peverly et al. (2007) is that they might not have measured the right component of working memory. There is not a great deal of unanimity about its definition (Logie, 2011), and individual differences in VWM have been hypothesized to be due to differences in capacity (Just & Carpenter, 1992), attention (Engle, 2001, 2002), and the long-term memory resources needed to process information in VWM (Cowan, 1999; Ericsson & Kintsch, 1995) and all of the above (Baddeley, 2000). Given the increasing acceptance of a multi-componential view of VWM, especially in writing (Vanderberg & Swanson, 2007), we included two working memory tasks, a complex span task of the type used in note-taking research (Cohn et al., Hadwin et al., and Peverly et al.) and in research on the development of academics skills (e.g., Swanson & Berninger, 1996) and one of the executive attention tasks, the Stroop, used by Engle (2001) in his research on working memory. Spreen and Strauss (1998) hypothesized that the Stroop measures selective attention and cognitive flexibility.

Summary

This study attempted to replicate the significant relationship of handwriting speed to note-taking (Peverly et al., 2007) and to extend them by investigating the effects of an outline on the relationship of handwriting speed to notes, as well as the relationship of language comprehension and VWM to notes. Last, this study sought to replicate the finding by Peverly et al. that notes mediate the relationship between other cognitive processes and test performance.

METHOD

Participants

Participants were undergraduates ($n = 204$) in an introductory educational psychology course at a large university in the northeastern USA, who participated for extra course credit. All participants were recruited in accordance with institutional review board procedures. A majority of the participants were sophomores ($n = 160$; 78.4%). None of the participants were psychology majors, although several had taken at least one psychology course ($M = 1.92$; $SD = 0.89$). The mean age was 20.81 years ($SD = 2.02$), 78.5% were women and 97.1% spoke English as their first language. Race/ethnicity as reported by participants was White (94.1%), Asian (2.9%) and Latino/a (2%). Because the Stroop task used in this experiment required students to read words in different colors, we asked students if they were color-blind. Four students (2%) indicated they were color-blind and were eliminated from the sample ($n = 200$).

Design

There was one between groups variable—Group (outline vs no outline). Students were randomly assigned to condition. There were several continuous variables included in the investigation: handwriting speed, language comprehension, two measures of working memory (span and attention), notes and written summary. Notes were both an independent and a dependent variable, and the written summary was a dependent variable only.

Materials

The materials consisted of the lecture video, lecture outline, written summary, the Nelson–Denny, a measure of handwriting speed, two measures of working memory, a complex span task (listening span) often used to measure capacity and a measure of attention (the Stroop). The names/initials in parentheses after some of the headings reflect how the variables are referred to in the remainder of the manuscript.

All measures were group administered. Inter-rater agreement (agreement / agreement + disagreement $\times 100\%$) was established for all measures. Two psychology graduate students independently scored a portion of the protocols for all measures. Disagreements were settled by consensus.

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 first author at a rate of 2.04 words per second, was approximately 23 minutes long and summarized basic concepts and research in the psychology of problem solving. The content of the lecture was adapted from a chapter by James 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 a total of six general themes and 15 content areas.

Outline

Students were randomly assigned to an outline or no-outline condition, hereafter referred to as 'Group'. The skeletal outline consisted of three sheets of paper with two headings per page, for a total of six headings, which corresponded to the lecture's major points. Examples of some of the headings were 'Introduction: The Importance of Problem Solving in Education' and 'Information Processing Theory'. Two of the six major headings had two subheadings. For example, the latter major heading had two subheadings: 'What is the definition of a problem?' and 'Research on problem solving'. The no-outline condition consisted of three blank sheets of unlined paper.

Note quality

Participants' notes were scored for quality. Quality scores reflected the rating (0–3) given to each of the 15 content areas mentioned in the no-outline condition and either (0–3) or (0–2) in the outline condition. In the no-outline condition, no points were given for incorrect or missing information, one point was given if a topic was mentioned but not elaborated on, two points were given for an incomplete explanation and three points were given for a complete explanation. For items in the outline condition where a score of two was the highest possible score, a rating of 0 was given for incorrect or missing information, 1 for an incomplete explanation and 2 for a complete explanation. Because the name of the topic was already provided for certain items in the outline section, an additional point for mentioning the topic was not given. The quality ratings for each of the 15 topics are specified in a manual created by Brobst (1996). For example, an individual would receive one point for writing down 'problem representation', one point for defining it and/or one point for giving an example related to the concept from the lecture. Quality scores could range from 0 to 45 for the no-outline condition and 0 to 41 for the outline condition. Given the differences between conditions in overall quality scores, raw scores were changed to percentages, by condition, for the analyses.

Inter-rater agreement for total scores across 30 randomly chosen protocols and across two independent scorers, consisting of both the outline and no-outline conditions, was 0.87.

Written summary

Participants were instructed to write an organized summary of the videotaped lecture without referring to their notes. They were allowed 15 minutes and given two sheets of paper for the task. The same method and criteria used for scoring the notes were used to score the essays. Given that participants in the outline condition could include information

from the headings and lecture in their summaries, the scoring rubric for the no-outline condition was used for both conditions (i.e., scores could range from 0 to 45). Raw scores were changed to percentages to enable comparison with notes' scores. Across 30 randomly chosen protocols and two independent scorers, inter-rater agreement was also 0.87.

Handwriting speed

This task is based on one used by Berninger, Mizokawa, and Bragg (1991) where children wrote as many letters of the alphabet as they could in 30 seconds. In the present study, participants wrote the letters of the alphabet horizontally on a lined sheet of paper, starting with 'a' and ending with 'z', as many times as they could in 45 seconds. One point was awarded for each recognizable letter, and the points were summated to calculate participants' total scores. Inter-rater agreement across 25 randomly chosen protocols was 1.0.

Language comprehension

Because listening and comprehension skills are highly correlated among college adults (Gernsbacher *et al.*, 1990), suggesting that reading and listening abilities are essentially the same construct in that population (Perfetti, 1986, 2007), language comprehension was assessed with the Comprehension component of the *Nelson–Denny Reading Test*, Form G (Brown, Fishco, & Hanna, 1993). The Nelson–Denny is a widely used, easily administered standardized reading test that is useful for screening reading skills, particularly in older students (Murray-Ward, 1998). The Comprehension component contains seven reading passages and 38 multiple-choice questions. Each question is followed by five possible answers. Reliability scores for the subtest are reported in the manual based on Kuder–Richardson on Formula 20 estimates, which yielded correlations ranging from .85 to .88 for students enrolled in a four-year college. Alternate form reliabilities yielded a correlation of .81 between the parallel forms of the Comprehension component. Under standard administration procedures, 20 minutes is allotted for this test. To increase the amount of variance in participants' performance, participants in the present study were only allowed 15 minutes to complete as much of the test as possible (Peverly & Sumowski, 2011). This variation was used to better discriminate between good and poor comprehenders (C. Perfetti, personal communication, February 3, 2003). Participants' answers to each of the 38 multiple-choice questions were scored as either correct or incorrect, and the total number correct was used in analyses. Total raw scores on this task could range from 0 to 38. Inter-rater agreement across 25 randomly chosen protocols and two independent raters was 0.96.

Verbal working memory

Verbal working memory was measured by two tasks, listening span and the Stroop. As discussed in the introduction, we measured VWM from two different theoretical perspectives: capacity or span (listening span test) and attention (Stroop).

Listening span test (span). The measure used to assess the span component of VWM was the listening span test (Daneman & Carpenter, 1980). Participants were presented with 60 unrelated sentences composed of five levels of

three sentence sets each via CD. The first level consisted of three sets of two sentences each. The next consisted of three sets of three sentences, and the last consisted of three sets of six sentences. As participants listened to each sentence, they had to determine whether the sentence made sense and circle 'Yes' or 'No' in their test packets. After each sentence set was completed, a beep signaled participants to recall and write down the last word of each sentence in that set. After 20 seconds, another beep sounded, signaling the beginning of the next sentence set. Participants were instructed not to write down any words until they heard the beep and not to write down the last word of the last sentence first.

The scoring of the listening span task followed the procedures laid out in Daneman and Carpenter (1980). Scores on this measure were based on the highest level (2–6) at which participants remembered all of the words for at least one of the three sentence sets. More specifically, if a participant correctly recalled all of the final words for two or all three of the sentence sets at level 4, but none at level 5 or 6, the student's score would be 4. If a participant correctly recalled all of the words for only one set at level 4, the score was the number of sentences in that set—.5 (3.5). However, for the initial set of sentences, participants received a score of 0 if they did not recall any words for any of the three sets of sentences and received a score of 1.5 for recalling all the words for only one set at level 2. Span scores could range from 0 and 1.5 to 6 in increments of .5. Inter-rater agreement for 25 randomly chosen protocols was 0.96.

Group Stroop (attention). The attention component of VWM was measured by the Group Stroop (Peverly & Sumowski, 2011). Although numerous versions of the original Stroop have been developed (see Lezak, Howieson, & Loring, 2004), the essential task requirements are the same. Individuals are asked to rapidly identify the ink color in which incongruous color names are printed (i.e., say 'blue' when the word 'red' is written in blue ink). Understood as a measure of selective attention and cognitive flexibility, Spreen and Strauss (1998) noted that the Stroop task assesses 'the ease with which a person can shift his or her perceptual set to conform to changing demands and suppress a habitual response in favor of an unusual one' (p. 213).

The Group Stroop is a paper-and-pencil measure adapted from the *Stroop Color and Word Test* developed by Golden (1978). Golden's test is individually administered and requires participants to respond orally. The Group Stroop, like Golden's version, consists of word reading, color naming and incongruent color-word naming.

All conditions began with task-specific instructions, sample items and practice items. Each condition consisted of 18 rows of five stimulus items each, totaling 90 items per condition. Each test item required participants to examine a stimulus on the left side of a box, make a judgment about the stimulus based on task-specific instructions and circle one of three possible response choices in the right half of the box (i.e., red, blue or green). On the word reading trial, participants were presented with a black, boldface color name on the left and were instructed to 'circle the word on the right that matches the word in bold on the left'. On the color naming trial, participants were presented with red, blue or green boldface

'XXX' on the left and were instructed to 'circle the name of the color on the right that matches the color on the left'. On the incongruent color-word trial, which is typically considered to be the measure of executive attention in the Stroop, and the one used in this study to measure executive attention, participants were presented with a boldface color name printed in red, blue or green ink and were again instructed to 'circle the name of the color on the right that matches the color of the ink on the left'. Participants were given 45 seconds to complete each condition. They were asked to work as quickly as possible until time expired. The score for each of the three trials was the total number of items answered correctly, with a range of 0 to 90. Inter-rater agreement across 25 randomly chosen protocols and two independent raters was 1.00.

To evaluate the validity of the Group Stroop, 13 graduate students were administered the Group Stroop and Golden's *Stroop Color and Word Test* (1978). The Group Stroop was administered first. Golden's Stroop was administered at least 10 days later. The validity of the incongruent color-word trial of the Group Stroop was assessed by correlating students' scores on this with their scores on the same trial of Golden's Stroop ($r = .89$, $p < .001$).

Procedure

The experiment took place over two days. On the first day, participants were randomly assigned to one of two conditions: outline or no outline. Participants in all conditions (i) read a consent form containing a statement of purpose, a description of the materials and procedures of the experiment, and statements as to how the experimenters would protect confidentiality (5 minutes), (ii) filled out a brief demographics questionnaire (5 minutes), (iii) watched and took notes on a lecture on the psychology of problem solving (via videotape; 23 minutes), (iv) reviewed their notes (10 minutes), (v) completed the handwriting speed task (1 minute) and a task measuring fine motor speed not included in the present analyses (1 minute), and (vi) wrote an organized summary about the lecture (15 minutes). On the second day, participants completed the span task (20 minutes), the attention task (Group Stroop; 10 minutes), the language comprehension measure (Nelson-Denny; 15 minutes) and a test of rapid automatized naming, which is also not included in the present analyses (2 minutes). Only those participants who completed all tasks in both sessions of the experiment were included in the analyses.

The fine motor task, mentioned earlier, was eliminated because a substantial number of subjects did not follow the directions sufficiently well to produce a sufficient corpus of valid data. The rapid automatized naming, which requires subjects to read multiple rows of some randomly ordered letters of the alphabet (s, d, a, p, o), was eliminated because of experimenter error.

RESULTS

There were 99 students in the outline group and 101 students in the no-outline group. MANOVAs were run to determine if there were differences between groups in demographics, or the independent and the dependent variables. The MANOVA with Group (outline vs no outline) as the independent variable

and students' demographic characteristics as the dependent variables (age, gender, ethnicity, English as a first language, year in college and major) was not significant (Wilks' $\lambda = .987$, $F(5, 192) = 0.507$, $p < .770$). Thus, there were no significant demographic differences between groups.

The MANOVA with Group as the independent variable and notes, written summary, handwriting speed, span, attention and language comprehension as the dependent variables was significant (Wilks' $\lambda = .840$, $F(6, 190) = 6.022$, $p < .001$, $\eta^2 = .16$). Follow-up ANOVAs with a Bonferroni correction ($p = .008$) indicated significant differences between groups on notes ($F(1) = 8.07$, $p = .005$, $\eta^2 = .04$) and the written summary, ($F(1) = 34.52$, $p < .001$, $\eta^2 = .15$). Participants in the outline group recorded and recalled more information from the lecture than the no-outline group. Means and standard deviations are presented in Table 1.

The intercorrelations among variables for all participants and for each group are presented in Tables 2 through 4. Group was significantly correlated with notes and the written summary. Notes were significantly correlated to handwriting speed, language comprehension and the written summary, whereas the written summary was significantly correlated to group, language comprehension and notes. There was one interesting difference in the correlations among variables for the outline and no-outline groups. Handwriting speed was significantly correlated with attention and language comprehension in the outline but not in the no-outline group.

A path analysis (IBM SPSS Amos 20 Armonk, NY, USA) was used to evaluate the relationship of all of the independent variables, including the interaction between Group and handwriting speed (GrxHSpeed), to notes and to determine if notes

Table 1. Means and standard deviations for the outline and no-outline groups

Variable	Outline ($n = 99$)		No outline ($n = 101$)		p
	M	SD	M	SD	
Notes ^a	45.63	10.73	40.81	12.91	.005
WS	8.70	3.34	5.93	3.27	<.001
HSPEED	93.12	17.33	95.50	18.28	.35
Span	3.89	1.46	3.80	1.39	.66
Attention	42.95	10.24	41.98	8.55	.47
LC	26.77	5.58	25.62	5.69	.16

Note: Notes, quality of notes; WS, written summary; HSPeet, handwriting speed; Span, listening span; LC, language comprehension.

^aThe means and standard deviations for notes are based in percentages.

Table 2. Intercorrelations among the independent and dependent variables ($N = 200$)

Variables	1	2	3	4	5	6	7
1. Group	—						
2. Notes	.18**	—					
3. WS	.38***	.49***	—				
4. HSPeet	-.07	.28***	.01	—			
5. Attention	.05	.12	.03	.22**	—		
6. LC	.10	.34***	.29***	.19**	.15*	—	
7. Span	.03	.09	.08	.05	.16*	.22**	—

Note: Notes, quality of notes; WS, written summary; HSPeet, handwriting speed; Span, listening span; LC, language comprehension.

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

completely mediated the relationship between the independent variables and test performance. Although we suspected that handwriting speed and Group would be significantly related to notes and that notes would be significantly related to test performance, our investigation was largely exploratory. We did not generate hypotheses about the relationships of the other variables to notes or to test performance, given the lack of guidance provided by the literature on note-taking. Thus, we ran a just-identified path analysis first ($\chi^2(0) = 0$; see Table 5 for a summary of the analysis) and then trimmed the model by eliminating non-significant paths on the basis of the outcome.

Parameter estimates for the model were generated using maximum-likelihood estimation. Several indices of fit are reported. The assumption of underlying bivariate normality was tested by the root mean error of approximation (RMSEA)

Table 3. Intercorrelations among the independent and dependent variables for the outline group ($n = 99$)

Variables	1	2	3	4	5	6
1. Notes	—					
2. WS	.45***	—				
3. HSPeet	.38***	.04	—			
4. Attention	.20	.06	.31**	—		
5. LC	.41***	.26*	.27**	.18	—	
6. Span	.07	.03	.01	.13	.21*	—

Note: Notes, quality of notes; WS, written summary; HSPeet, handwriting speed; Span, listening span; LC, language comprehension.

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

Table 4. Intercorrelations among the independent and dependent variables for the no-outline group ($n = 101$)

Variables	1	2	3	4	5	6
1. Notes	—					
2. WS	.47***	—				
3. HSPeet	.23*	.05	—			
4. Attention	.03	-.04	.13	—		
5. LC	.27**	.29**	.14	.20	—	
6. Span	.11	.13	.10	.16	.24*	—

Note: Notes, quality of notes; WS, written summary; HSPeet, handwriting speed; Span, listening span; LC, language comprehension.

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

Table 5. Summary of the just-identified path model

Structural path	Estimate	SE	CR	p
Notes $\leftarrow$ Group	4.15	1.55	2.68	.007
Notes $\leftarrow$ Hspeed	0.13	0.06	2.12	.034
Notes $\leftarrow$ GrxHSPeet	0.06	0.09	0.66	.512
Notes $\leftarrow$ Span	0.12	0.57	0.21	.833
Notes $\leftarrow$ Attention	0.03	0.08	0.34	.731
Notes $\leftarrow$ LC	0.60	0.15	4.16	<.001
WS $\leftarrow$ Notes	0.13	0.02	6.85	<.001
WS $\leftarrow$ Hspeed	-0.01	0.02	-0.87	.383
WS $\leftarrow$ Attention	-0.01	0.02	-0.62	.536
WS $\leftarrow$ Group	1.81	0.42	4.28	<.001
WS $\leftarrow$ Span	-0.01	0.15	-0.01	.991
WS $\leftarrow$ LC	0.10	0.04	2.39	.017
WS $\leftarrow$ GrxHSPeet	-0.02	0.02	-0.69	.490

Note: Notes, quality of notes; WS, written summary; HSPeet, handwriting speed; Span, listening span; LC, language comprehension.

fit index. An RMSEA value lower than 0.05 indicates a close fit of the model, relative to the degrees of freedom, and no serious effects of non-normality. The proportion of improvement in the fit of the model over the null model was evaluated using the Normed Fit Index (NFI), the Comparative Fit Index (CFI) and the Tucker–Lewis Index (TLI). All three are interpreted in approximately the same way, although the CFI is less affected by sample size than the NFI, and the TLI includes a correction for model complexity (and is the only one that can fall outside the range of 0–1). All three should be greater than 0.95, which indicates that the fit of the researcher's model is 95% better than the null model.

The trimmed model is presented in Figure 1. The goodness of fit indices were very good: $\chi^2(7) = 5.03$, $p = .656$, CFI = 1.00, RMSEA = 0.00, NFI = 0.98, TLI = 1.04. Path significance was based on critical ratios (CR). A critical ratio greater than 1.96 is considered to be significant at $p = .05$. The analysis indicated that Group (CR = 2.70, $p = .007$), language comprehension (CR = 4.40, $p \leq .001$) and handwriting speed (CR = 3.48, $p \leq .001$) predicted notes and that notes (CR = 6.48, $p \leq .001$), Group (CR = 4.52, $p \leq .001$) and language comprehension (CR = 2.14, $p = .033$) predicted test performance. None of the other variables were significant.

DISCUSSION

The present study had two purposes. The first was to determine whether cognitive processes other than handwriting speed, specifically language comprehension and working memory (span and/or attention), were related to notes' quality. Related to the first, we sought to determine if an outline of the lecture might reduce or eliminate the relationship of handwriting speed to notes. Second, we sought to replicate the finding by Peverly et al. (2007) that notes mediate the relationship between other cognitive processes and test performance.

Cognitive processing and prediction of notes' quality

With the exception of the lack of a relationship between working memory and either notes or the written summary,

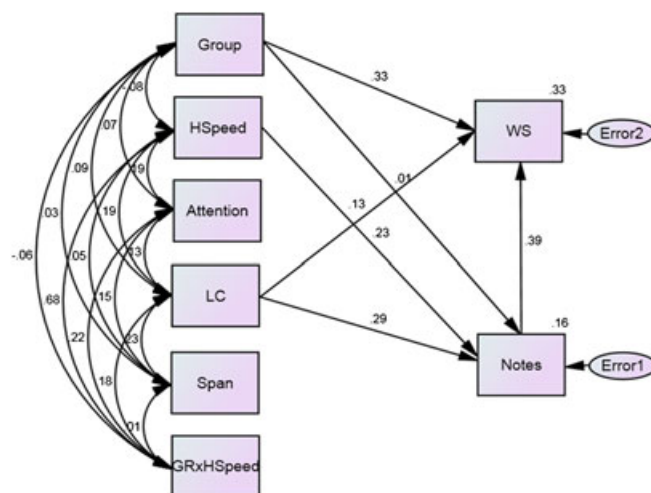


Figure 1. Path analysis of the relationships between Group, HSpeed (handwriting speed), Attention, LC (language comprehension), Span, GRxHSpeed (Group $\times$ handwriting speed interaction), Notes and WS (written summary)

our results suggest that skilled performance in note-taking is similar to skilled performance in other academic skills. Theory and research on academic skills such as writing (Berninger et al., 2006; McCutchen, 1996), reading (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004) and mathematics (Geary, 1994) agree that competence requires the parallel execution of domain-specific basic and higher level processes within a limited capacity working memory. Specifically, domain-specific basic skills must be automatic/fluent, so as not to burden the limited resources of working memory. In addition, higher level skills such as language comprehension must also be well developed so that they can be used to interpret/analyze the information held in working memory to achieve the goal of the activity (e.g., comprehension). The data from this study suggest that skilled note-taking requires 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. A detailed discussion of each variable, including the conundrum of working memory, follows.

Handwriting speed

Handwriting speed is important to different forms of writing. In the domain of essay writing, a growing body of research suggests a positive and significant relationship between handwriting speed and writing outcomes for individuals of all ages. Whether focusing on individual differences in handwriting speed (all ages), instruction in handwriting speed (children only) or the experimental manipulation of handwriting speed (via the manipulation of writing scripts; adults only), research with elementary and middle school children (Berninger et al., 1997; Graham et al., 1997; Graham et al., 2000; Jones & Christensen, 1999; Olinghouse & Graham, 2009; Olive, Favart, Beauvais, & Beauvais, 2008) and adults (e.g., Brown et al., 1988; Connelly et al., 2006; Connelly et al., 2005; Olive et al., 2009; Olive & Kellogg, 2002) has found a significant relationship between handwriting speed and ratings of the quantity and quality of participants' essays and other writing outcomes. Data from the present study, the two experiments in Peverly et al. (2007) and a recently published study on the cognitive processes underlying *text* note-taking, which found that handwriting speed is related to the quality of text notes (Peverly & Sumowski, 2011), extend these results to a different domain—note-taking. Thus, handwriting speed appears to be important to writing outcomes of different types: essays, lecture notes and text notes.

The outline, however, did not moderate the significant relationship between handwriting speed and notes (i.e., the handwriting speed $\times$ group interaction was not significant). It is not clear to us why this is the case. It may be related to the rate and conditions of the lecture. Because the lecture was read from a prepared text and did not have some of the natural breaks that occur in real classrooms such as students' and teachers' questions, the rate of the lecture may have been too rapid for an outline to compensate sufficiently for slow fluency. Thus, until these processes are evaluated under more realistic conditions, both fluent handwriting and outlines seem to be independently related to the amount of information in notes.

We have one final thought about handwriting speed. There is some question about what the alphabet task used in this investigation and many other investigations actually measures (Abbott & Berninger, 1993). Given the requirements of both manual movements and speed, logically speaking, it should be related to fine motor speed. However, the alphabet task also requires knowledge of the alphabet. Because college students know the alphabet, we hypothesized that individual differences might be related to how quickly they could access alphabetic (verbal) codes. In a series of three studies, Peverly & Vekaria (in preparation) investigated whether handwriting speed was related to fine motor speed and the speeded access of alphabetic codes (each study included other cognitive variables; e.g., VWM). Results indicated that undergraduates' handwriting speed was significantly related to both variables but not to any others. For comparable results with children, see Berninger *et al.* (2006).

Language comprehension

Language comprehension is a critical component of idea generation in narrative, expository and other forms of essay writing (McCutchen, 2012). Although note-taking is a much more passive activity than essay writing, cognitive task analyses of note-taking suggest that language comprehension should also be significantly and positively related to the quantity and quality of information in students' lecture notes (Kiewra & Benton, 1988; Kiewra *et al.*, 1987; Kobayashi, 2005; Peverly, 2006; Piolat *et al.*, 2005). Prior research, however, has not found a significant association between language comprehension and note-taking (Kiewra *et al.*, 1987; Kiewra & Benton, 1988; Peverly *et al.*, 2007). As discussed earlier, methodological flaws might explain the findings by Peverly *et al.* (2007), but it is not clear why Kiewra and colleagues did not find a relationship between students' ACT scores and note-taking. One possibility is that their participants' ACT scores were not sufficiently variable. That is difficult to judge, however, because the means and standard deviations were not provided. In that vein, we shortened the recommended amount of time students had to complete our measure of language comprehension, to increase the variation related to ability. Regardless, the data reported here are the first to demonstrate a significant relationship between lecture notes and language comprehension. This finding has been verified in two unpublished dissertations (Gleason, 2012; Vekaria, 2011). In both, language comprehension was found to be significantly related to the quality of notes among students with and without a self-reported diagnosis of attention deficit/hyperactivity disorder either in high school (Gleason, 2012) or in college (Vekaria, 2011). Thus, as speculated earlier, language comprehension may be (i) as important to note-taking as it is to writing essays and (ii) related to notes once handwriting speed is sufficiently developed.

Working memory

Given the time-limited and resource demanding nature of lecture note-taking, and the great deal of research that has found a relationship between WM difficulties and problems with academic skills, behavior, attention and problem solving, among other difficulties (e.g., Alloway, Gathercole, Kirkwood, & Elliot, 2009; Gathercole, Alloway, Willis, &

Adams, 2006), it is a bit perplexing that working memory has not been found to be significantly related to note-taking in either this investigation, regardless of the measures used to assess it, or prior research (Cohn *et al.*, 1995; Hadwin *et al.*, 1999; Peverly *et al.*, 2007; Cohn *et al.*, 1995).

There are three possible explanations. First, the attention and span measures we used were developed for individual administration, but adapted for group administration, which may have introduced error. However, Cohn *et al.* (1995) and Hadwin *et al.* (1999) used individually administered complex span tasks and did not find a significant relationship between working memory and notes. Also, we just completed a study on lecture note-taking where we administered both tasks individually (Peverly, Garner, & Vekaria, under review) and did not find a significant relationship between notes and either span or attention.

Another possible explanation is that we measured the wrong component of executive attention. Executive attention is a broad construct, and some have argued that the Stroop measures one aspect of executive attention, response control and inhibition (Spree & Strauss, 1998), which may be less important to note-taking than another component of executive attention, sustained attention. Sustained attention is conceptualized as the ability to maintain attention, for example to lectures, for long periods (Lezak *et al.*, 2004; Posner & Peterson, 1990). In the two unpublished dissertations mentioned earlier (Gleason, 2012; Vekaria, 2011), there was a significant relationship between sustained attention and notes among college (Vekaria, 2011) and high school students (Gleason, 2012), with and without the diagnosis of attention deficit/hyperactivity disorder.

A third reason may be that individual variation in real-world tasks such as note-taking and narrative writing are related to individual variations in long term memory (LTM) resources (Kintsch, 1998), such as handwriting speed and language comprehension, and not to the capacity limitations of working memory (for similar arguments in the writing literature, see Kellogg, 2008 and McCutchen, 2000). One LTM variable that has been consistently related to working memory (Chi, Glaser, & Farr, 1988; Kintsch, 1998) is background knowledge, which was not included in this study. Future research on the cognitive processes underlying note-taking should include background knowledge to determine if including it creates a significant relationship between working memory and notes or test performance.

Prediction of test performance

Our data suggest that students' performance on the written summary was not totally mediated by notes. Group and language comprehension were also significant predictors. Regarding notes, it was expected that notes would be significantly related to students' written recall given the findings from past research (Bretzing & Kulhavy, 1981; Fisher & Harris, 1973; Kiewra *et al.*, 1991; Kiewra & Fletcher, 1984; Peverly *et al.*, 2003; Rickards & Friedman, 1978; Titsworth & Kiewra, 2004). Although notes typically contain 20% to 40% of the information presented in a lecture (e.g., Armbruster, 2009; Kiewra, DuBois, Christensen, Kim, & Lindburg, 1989), the contents of notes are strongly biased toward important information (Kiewra *et al.*, 1987; Kiewra & Fletcher, 1984). Because

students are more likely to recall information recorded in their notes than information that was not recorded (Bretzing & Kulhavy, 1981; Kiewra et al., 1987), students with better notes are generally able to produce better written recall.

The finding that providing students with a skeletal outline improved students' written recall also confirms previous research (see Armbruster, 2009; Kiewra, 1991, for reviews). As discussed previously, outlines may help students construct a better representation or macrostructure of the lecture (Kiewra et al., 1991; Lorch et al., 1985), which in turn may have helped them create a better written summary.

In comparison to variables such as notes or techniques used by instructors and researchers to improve notes such as outlines, very little research on note-taking has focused on the cognitive processes that affect test performance directly, in addition to those that have an indirect effect on performance through notes (e.g., handwriting speed). The cognitive variables that have been found to be related to test performance in previous research, other than notes, are background knowledge (Cohn et al., 1995; Peper & Mayer, 1986; Peverly et al., 2003; Peverly & Sumowski, 2011), working memory (Cohn et al., 1995) and general ability (Scholastic Aptitude Test (SAT); Cohn et al., 1995). The latter findings using the SAT, which has a verbal component, and our results, suggest that language comprehension may also be related to good test performance. If confirmed in future research, language comprehension, like outlines, may help students construct a better global, hierarchical representation of important verbal information (Kintsch, 1998; Perfetti, 2007), which in turn may help them write a good summary.

Conclusions, limitations and future research

Recent research on lecture note-taking has found a few variables that are related to lecture notes: information processing ability (Kiewra & Benton, 1988; Kiewra et al., 1987), handwriting speed (Gleason, 2012; Peverly et al., 2007; this study), language comprehension (Gleason, 2012; Vekaria, 2011; this study) and sustained attention (Gleason, 2012; Vekaria, 2011). Similar results have been found in research on text note-taking (Peverly & Sumowski, 2011). Collectively, these findings indicate that (i) despite the differences between essay writing and note-taking, they share some of the same cognitive processes, and (ii) Peverly et al. (2007) were wrong; notes do not mediate completely the relationship between students' cognitive processes and test outcomes.

Regarding test performance, the range of tests included in research that has evaluated the relationship of multiple cognitive processes to notes and test performance is relatively narrow: written summaries and multiple-choice exams. In the latter, two item types were used, those that measured (i) information stated directly in text, and (ii) inferences, the ability to go beyond the text to understand concepts and relationships not explicitly stated in text. According to Kintsch (1998), tests such as written recall and multiple-choice items that assess information stated directly are measures of memory but not necessarily understanding, because they have not explicitly assessed understanding. Tests that measure inferences, however, are measuring whether students have more deeply processed and enriched the information presented in lecture

by integrating that information with general and domain-specific knowledge, world experiences etc. In Kintsch's view, tests that measure inferences are measures of understanding. The prediction patterns in the aforementioned studies suggest a very tentative model of the relationships among the cognitive variables related to note-taking and test-taking, which is presented in Figure 2.

There are a number of implications for future research. First, because the number of studies on the cognitive processes of note-taking is relatively few, the cognitive processes found to be related to notes and test performance need to be verified in future research, and other constructs and processes need to be investigated. Thus, future research should test the model presented in Figure 2. Another possible avenue for future research is related to the note-taking function of review. In this investigation, we evaluated the relationship of test performance to notes and all of the other variables included in our investigation (Figure 1). However, our measure of notes is a measure of students' encoding of the information presented in lecture, not their review of the material, even though students were allowed time for review. Given that note-taking has two functions, encoding and review (DiVesta & Gray, 1972), and reviewing is typically more strongly related to test outcomes than encoding (Kobayashi, 2006), future research should measure the cognitive processes related to both functions and evaluate their relationship to test performance separately. To date, we are aware of only one study that attempted to evaluate the cognitive processes that underlie both functions (Hadwin et al., 1999).

Second, the variable of attention is a complicated construct that has not received the consideration it deserves in investigations of note-taking. We used the Stroop to explore the relationship of the response control and inhibition components of executive attention to note-taking and did not find a significant relationship. However, there are other components of attention that have a considerable degree of face validity in activities such as lecture note-taking. Posner and Peterson (1990), for example, argue that attention consists of orienting or selective attention, alerting or achieving and sustaining an alert state, and executive control, which resolves conflicts among responses. The data from Gleason (2012) and Vekaria

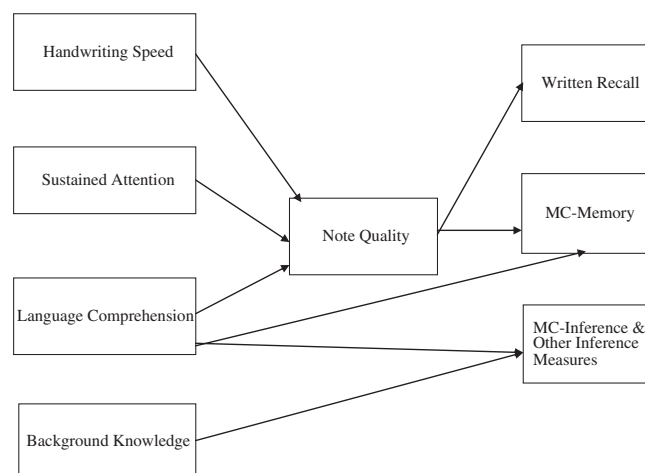


Figure 2. Hypothesized relationships among cognitive processes, notes and test performance

(2011) suggest that sustained attention is related to notes' quality in both high school and college students. All three components of attention should be investigated more thoroughly.

In addition, the positive and significant relationship between handwriting speed and text production in writing and note-taking may be related to the nature of English orthography and/or the lack of emphasis on handwriting instruction in US elementary schools. Handwriting speed has not been found to be related to competency in writing essays in Turkish. Turkish has a shallower orthography than English (i.e., simpler symbol to sound correspondences), which can make spelling, and thus writing, easier (Treiman & Kessler, 2005). Also, Turkey has a stronger emphasis on instruction in handwriting than the USA (Babayigit & Stainthorp, 2011). Instruction in handwriting is significantly and positively related to good quality essays (Berninger *et al.*, 1997; Graham *et al.*, 2000; Jones & Christensen, 1999). Future research should evaluate whether transcription is universally related to notes by directly comparing notes taken in a relatively deep (e.g., English) and a relatively shallow orthography (e.g., Spanish).

To continue with the variable of transcription fluency, research suggests that students' notes are generally quite sparse often containing less than 40% of the information in lecture, and sometimes much less (Armbruster, 2009). In part, this seems to be due to the speed of lectures. In an ongoing survey on note-taking among college undergraduates we are conducting, the second most common response to the question on the conditions under which students might take better notes is slower lectures. This in turn suggests that students are writing what they can, when they can, without paying much attention to existing notes as a guide to current note-taking. However, we do not know that for sure. Research on essay writing has been focusing a great deal of attention on the cognitive processes related to the influence of reading what has been written so far on subsequent writing (Alamargot, Chesnet, & Caporossi, 2012). This could prove to be a very fruitful area of research in note-taking.

Finally, technology use is now ubiquitous in classrooms. Many students use laptops, notepads, note-taking pens and other devices to take notes. We have no idea how efficacious these devices are in comparison to taking notes with paper and pen and whether the cognitive processes that underlie the use of these are different than those that underlie the use of paper and pen. This should be investigated. Also, instructors use software (e.g., PowerPoint) and technology (e.g., Smart Boards) that may have a strong impact on note-taking and should be systematically investigated for their impact on note-taking and students' performance in school.

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