The role of working memory abilities in lecture note-taking☆

Dung C. Bui *, Joel Myerson *

Department of Psychology, Washington University in St. Louis St. Louis, MO 63130, United States

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The utility of lecture note-taking is well documented, with most studies dedicated to understanding how to maximize the benefits of note-taking. Far less attention has been focused on understanding the cognitive processes that underlie note-taking and how the benefits of note-taking vary with individual differences in the ability to carry out these processes. One cognitive ability that has been hypothesized to be important for note-taking is working memory: the ability to temporarily store and manipulate limited amounts of information. The current paper addresses why working memory is important for lecture note-taking and reviews studies that have examined the relationship between individual differences in working memory abilities and individual differences in note-taking. There is currently a lack of consensus regarding the nature of this relationship, and this review addresses possible reasons for what may appear to be inconsistent results, including differences in how working memory and its role in note-taking have been assessed, note-taking modality, and individual differences in note-taking strategy.

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1. Introduction

The process of note-taking is familiar to just about everyone. Although note-taking occurs in both academic and non-academic contexts, the positive consequences of note-taking are most clearly evident in educational situations where students are evaluated on the basis of how much information they can retain from lectures. Indeed, note-taking has long been linked to positive test performance (e.g., Armbruster, 2009; Crawford, 1925). This relationship is not lost on students, who acknowledge lecture note-taking as a crucial component of the educational experience (Dunkel & Davy, 1989). In fact, lecturing constitutes more than 80% of college instructors’ teaching methods (Wirt et al., 2001), and therefore it should not be surprising that nearly all college students take notes in class (Palmatier & Bennett, 1974; Van Meter, Yokoi, & Pressley, 1994), even when they are not explicitly told to do so by the instructor (Williams & Eggert, 2002).

2. A brief overview of lecture note-taking research

DiVesta and Gray (1972) proposed that note-taking facilitates learning in two important ways, providing not just what these authors termed an external storage benefit, but providing in addition what they termed an encoding benefit. More specifically, they argued that note-taking does not just help by recording lecture information for us to restudy later; importantly, note-taking also helps at the time of the lecture by promoting the encoding of information in ways that facilitate later retrieval (e.g., by encouraging deeper processing of lecture information, as suggested by Kiewra, 1985). DiVesta and Gray's seminal paper stimulated considerable research on note-taking concerned with assessing the independent contributions of encoding and storage to the overall effects of lecture note-taking and with determining which of these processes plays a larger role in driving the benefits of note-taking.

In most of the studies exploring the encoding benefit, students listened to a lecture and were randomly assigned to groups which either took notes during the lecture or just listened without taking notes. In order to isolate the encoding benefit, students in these studies were not allowed to review their notes prior to being tested for their memory of the lecture material. A review by Kiewra (1985) identified 56 such studies, of which 33 found a beneficial effect of note-taking. In short, a significant effect was observed in most cases, but the evidence for an encoding benefit from note-taking was far from unanimous. Moreover, although knowing that an effect is observed 59% of the time speaks directly to its replicability, it provides only indirect evidence of the size of the effect. After all, effects can be inconsistent, perhaps because of unspecified moderating variables, and yet be large when they occur.

To address these issues, Kobayashi (2005) conducted a meta-analysis of studies that compared no note-taking to note-taking without restudy. Overall, Kobayashi found a small positive effect of note-taking (Cohen's $d = .26$), consistent with the results of Kiewra’s (1985) review. Importantly, however, the largest effect sizes were observed for free recall tests, whereas the smallest effects (not counting cases where the type of test could not be determined) were for recognition...
testing (average Cohen's $d$s for free recall and recognition tests of .55 and .18, respectively).

Examining a number of other potential moderator variables, Kobayashi observed that the encoding benefit was smaller when the presentation mode could be visually distracting, as in the case of an actual or filmed lecturer, compared to an auditory recording. Noting that previous research indicated that presentation mode does not affect learning from lectures when notes are not taken, Kobayashi concluded that in studies of note-taking, presentation mode may moderate the encoding benefit because writing requires visual attention (e.g., to prevent going off of the page), and thus attention to other visual stimuli may limit the ability to take handwritten notes.

Kobayashi’s (2005) interpretation is consistent with research showing that note-quantity is a powerful predictor of test performance even when students are not allowed to reread their notes (e.g., Aiken, Thomas, & Shennum, 1975; Fisher & Harris, 1973). For example, Bui, Myerson, and Hale (2013), following up on prior findings showing that (except in novices) typing is usually faster than handwriting (Brown, 1988), had participants take lecture notes either by typing on a computer keyboard or by writing them. When participants were told to try and transcribe a lecture, typing using a computer not only led to greater note-quantity compared to taking handwritten notes, it also led to better memory for the lecture material. Moreover, similar effects of note-quantity are obtained when students are allowed to study their notes (e.g., Crawford, 1925; Kiewra & Benton, 1988; Kiewra, Benton, Kim, Risch, & Christensen, 1995; Nye, Crooks, Powley, & Tripp, 1984). For example, in two experiments in which study time was given, Peverly et al. (2007) found that transcription speed, as measured by both an adapted version of the alphabet task (Berninger, Mizokawa, 1989), Kiewra (1985) pointed out that from the perspective of advancing age function was more important (e.g., Fisher & Harris, 1973; Howe, Barnett, DiVesta, & Rogozinski, 1981), others reported the external storage function was more important (e.g., Fisher & Harris, 1973; Howe, 1970; Kiewra et al., 1991; Rickards & Friedman, 1978). However, because utilizing both aspects of note-taking in conjunction appears to be a more potent learning tool than either aspect on its own (e.g., Fisher & Harris, 1973; Kiewra, DuBois, Christensen, Kim, & Lindberg, 1989), Kiewra (1985) pointed out that from the perspective of advancing educational instruction, it may serve little purpose to focus solely on comparing each component’s contribution.

3. Cognitive demands in lecture note-taking

Despite its benefits, lecture note-taking can be cognitively demanding, as it typically involves students having to pay attention to a lecture, temporarily holding onto the information provided while simultaneously organizing that information, and then having to write it down before it is forgotten. Perhaps as a result, students may adopt different note-taking strategies whose effectiveness can vary for a number of reasons, among them being individual differences in cognitive ability. That is, the degree of efficiency with which certain cognitive operations can be performed varies from one individual to another, and these individual differences influence how well people are able to perform a complex task such as note-taking.

One cognitive ability that seems like it should be important for lecture note-taking is working memory, which has been defined as the ability to temporarily hold and manipulate limited amounts of information (Baddeley, 1986, 2007). Early conceptualizations of working memory tended to focus on short-term storage and rehearsal (e.g., Atkinson & Shiffrin, 1968). Newer conceptualizations, however, cover much more than this, and accordingly, working memory has been extensively studied under conditions that require not just maintaining items in memory, but also coordinating and switching back and forth between multiple tasks (e.g., Baddeley, Chincotta, & Adlam, 2001; Engle, Tuholski, Laughlin, & Conway, 1999). Such multi-tasking is obviously a fundamental aspect of lecture note-taking, and indeed, holding onto information while multi-tasking is, at least for some researchers, the very essence of working memory (Engle et al., 1999).

It should be noted, however, that the term working memory has been used in quite different ways by different researchers. For example, some cognitive neuroscientists, particularly neurophysiologists, have studied working memory using tasks that require temporary maintenance of only a single item (e.g., a spatial location or to-be-remembered response; for a review, see Goldman-Rakic, 1996). Other cognitive neuroscientists, particularly those using neuroimaging, have used n-back tasks that require constant updating of information about the most recent n items (for a review, see Owen, McMillan, Laird, & Bullmore, 2005). Experimental psychologists and individual-differences researchers have studied working memory using both traditional memory span tasks and complex span tasks that interleave irrelevant processing tasks with presentation of to-be-remembered items (Conway et al., 2005).

Both the difference, if any, between the abilities tapped by simple and complex span tasks and the role of these abilities in higher-order cognition remain controversial (e.g., Colom, Rebullol, Abad, & Shih, 2006; Engle et al., 1999; Unsworth & Engle, 2007b). In addition, n-back tasks and complex span tasks have proved to be only weakly correlated (Redick & Lindsey, 2013). As a result, we have chosen to use a broad definition of working memory here, and to review the literature that examines a variety of functions (e.g., the storage, forgetting, and transformation of temporarily stored information) that are included in current models of working memory, even if the tasks used to assess these functions tap only one aspect of what some researchers would consider working memory.

Perhaps the most well-known model of working memory is that of Baddeley’s (1986; Baddeley & Hitch, 1974), who proposed that the working memory system includes not only content-specific storage components (the phonological loop and visuo-spatial sketchpad for verbal and visuospatial information, respectively), but also a processing component (the central executive) that performs a wide range of functions, including directing attention to relevant information, inhibiting irrelevant information and/or actions, and coordinating cognitive processes when more than one task must be done at the same time. More recently, Baddeley (2000) added a new component, the episodic buffer, to his model to allow for the interaction between the two storage components, as well as to account for the contributions of long-term memory to performance on working memory tasks.

Baddeley’s (1986, 2007) model has been successful in explaining many findings in the short-term and working memory literature, as well as in stimulating further research. More recently, however, other models have emerged that provide alternative accounts of the processes that underlie working memory function. These models differ with regards to issues such as the contribution of long-term memory to working memory function, the nature of working memory’s limited capacity, and the role of attention in working memory (for reviews of various models and theories, see Conway, Jarrold, Kane, Miyake, & Towsn, 2007; Miyake & Shah, 1999).
For example, Unsworth and Engle (2007a) proposed that individual differences in working memory ability reflect differences in the ability to retrieve information under situations of high interference. Following Cowan (1988, 1995), they argued that the amount of information we can actively maintain in our focus of attention, or primary memory, is limited to about four items, and that additional items must be retrieved from what they termed secondary memory. Working memory tasks like reading span (Daneman & Carpenter, 1980), in which one must remember the last words of a series of sentences, depend on retrieving items from secondary memory because the processing of each new sentence displaces the last word of the previous sentence from primary memory. Unsworth and Engle posited that individuals with better working memory ability have higher spans largely because they are better able to use cues to search secondary memory for these displaced items.

Central to almost all models of working memory are two ideas critical to understanding individual differences in note-taking: First, the storage capacity of working memory is limited, and second, working memory functions consist of not just temporary storage, but also the manipulation and/or transformation of what is stored, and the maintenance of temporarily stored information when attention is shifted to performance of other tasks. These additional functions have been described as being executive in nature, in that they encompass processes involved in the control of other cognitive processes.

The emergence of executive functions has been shown to correspond to the development of the frontal lobes (De Luca & Leventer, 2008; Fuster, 2002), and individual differences in executive function have been hypothesized to underlie the relation between working memory and higher cognitive functions (Kane & Engle, 2002). Multiple working memory tasks have been developed that are hypothesized to assess executive functions, and these tasks have proved to be good predictors of higher order abilities such as reading comprehension (Daneman & Carpenter, 1980; Daneman & Merikle, 1996), fluid intelligence (Engle et al., 1999; Kane & Engle, 2002), and complex learning (Shute, 1991; Tamez, Myerson, & Hale, 2012). Like working memory, however, executive functions are not monolithic, but comprise different abilities, and thus it is possible that, in addition to storage abilities, a given working memory task may tap more than one executive function.

### 4. Individual differences in working memory and note-taking

The idea that working memory and lecture note-taking tap similar cognitive processes has high face validity. For example, the ability to temporarily store and manipulate information is part of the definition of working memory (Baddeley, 1986) and would appear to be very important in note-taking as well. When students take notes during a lecture, they often need to hold onto what the instructor is saying while they try and organize it and paraphrase it more succinctly. Another process that working memory and note-taking ability both seem to rely on is task switching. One type of task commonly used to assess working memory ability, the complex span task (e.g., counting span, operation span), requires individuals to continuously switch back and forth between a memory task and a processing task (Case, Kurland, & Goldberg, 1982; Turner & Engle, 1989). Similar demands are placed on students when they take notes during a lecture and have to switch back and forth between listening to the instructor and writing down their notes, except when they can do both simultaneously, in which case they are using another ability tapped by some working memory tasks—dual-task coordination (Baddeley, 1986).

Despite the apparently similar cognitive demands of working memory and note-taking tasks, to date there have been relatively few empirical studies examining the link between them, and the studies that have examined this relationship have produced mixed results. Some studies have reported that working memory and note-taking abilities are correlated (e.g., Hadwin, Kirby, & Woodhouse, 1999; Kiewra, Benton, & Lewis, 1987; McIntyre, 1992), whereas other studies have failed to support this relationship (e.g., Pevery et al., 2013). The present review will describe the studies that have explored the relationship between working memory and lecture note-taking, and discuss possible reasons for some of the reported inconsistencies.

To begin with, studies examining the link between working memory and note-taking have measured working memory ability in a variety of ways, and performance on working memory tasks appears to depend on multiple abilities (e.g., Conway et al., 2007; Hale et al., 2011; Oberauer, Süß, Wilhelm, & Wittman, 2003). In studies involving note-taking, working memory has been measured using short-term memory tasks that focus on temporary storage ability, information-processing tasks that assess the ability to reorganize information, and complex span tasks that test the ability to multi-task while holding onto new information. The findings obtained using each of these approaches have implications for different aspects of the relationship between working memory and note-taking.

#### 4.1 Short-term storage and forgetting

One of the first studies to explore the relationship between working memory and note-taking was conducted by DiVesta and Gray (1973), who were interested in the effects of thematic relatedness and continuity on lecture note-taking. In their study, participants were instructed to take notes while listening to six 5-min lecture segments. A free recall test was administered immediately after the last segment ended, followed by a true-false test. Participants returned a week later to take a second true-false test with test items not included on the previous test. During the second session, DiVesta and Gray also administered a Brown–Peterson task (Brown, 1958; Peterson & Peterson, 1959), which measures short-term storage, a construct that has been shown to be highly correlated with measures of working memory (Engle et al., 1999; Unsworth & Engle, 2007b). In this task, participants counted down by threes from some large number during a retention interval. Scores on this task provide a measure of the rate of forgetting over the short-term.

In the condition most similar to students’ actual classroom experience, a single 30-min lecture was simply divided into six successive segments. Under these circumstances, the scores on the Brown–Peterson task for participants who took notes were positively correlated with their performance on the delayed true-false tests, whereas for those who heard the same lecture but did not take notes, the correlation was close to zero. Based on these results, DiVesta and Gray (1973) concluded that individuals with greater memory spans benefit more from note-taking than those of lower ability.

Because working memory necessarily involves short-term storage, DiVesta and Gray’s (1973) study can be interpreted as being one of the first to suggest that individual differences in working memory may play a role in lecture note-taking. However, two things should be noted. First, although the results of the study suggest that the benefits one obtains from taking notes depend on one’s working memory ability, the study does not provide any insight into exactly how working memory ability influences the note-taking process. Such insight requires actually examining participants’ lecture notes in order to see in what ways they differ. For example, higher working memory ability individuals may simply take more notes than lower ability individuals. Second, DiVesta and Gray claimed to have found a relationship between individuals’ memory span and the benefits they obtain from note-taking, but the Brown–Peterson task that they used measures the rate of forgetting from short-term memory rather than memory span. Unfortunately, to the best of our knowledge, to date no studies have directly examined the relationship between note-taking and memory span as measured by traditional short-term memory tests (e.g., digit span, word span).

#### 4.2 Processing and reorganizing information

Researchers soon moved beyond measures of short-term storage and forgetting in their effort to explain individual differences in note-taking ability. In particular, Benton, Kraft, Glover, and Plake (1984)
developed measures influenced by the theory of discourse processing proposed by van Dijk and Kintsch (1983). According to this theory, readers build three different mental representations of a discourse: a surface form representation of the discourse, a “text” base representation that captures the propositional structure of the text, and a situational model of the situation to which the text refers. Deeper comprehension is hypothesized to require not only a coherent text base, but also a coherent situation model.

Based on van Dijk and Kintsch’s (1983) theory, Benton et al. (1984) developed three measures of the ability to reorganize information, an ability critical to building mental representations, of which two have been used in note-taking research: the word-reordering task and the sentence-reordering task. In the word-reordering task, participants view sentences in which the words are out of order, and they are required to rearrange them to create meaningful sentences. In the sentence-reordering task, participants view paragraphs in which the sentences are out of order, and they are required to rearrange the scrambled sentences to make meaningful paragraphs. Although these tasks were initially developed in order to study differences in writing ability, scores on both the sentence-reordering task and the word-reordering task have since been used to assess individual differences in the process of manipulating information, which is believed to play a crucial role in both working memory and lecture note-taking.

Kiewra et al. (1987) were the first to examine how well performance on one of these information-processing tasks could predict note-taking in lectures. They conducted their study over a four-week period during which the students in an Educational Psychology course were given a series of twelve 50-min lectures. Immediately following the eighth lecture, the students’ notes were collected and photocopied, and then returned two days later. Five days after the students got their notes back, they were given a multiple-choice test on that lecture, and then three weeks later, they were given a course exam that covered all twelve lectures. Scores on the sentence-reordering task (administered prior to the first lecture) correlated positively with both the number of words and the number of idea units in students’ notes, which in turn predicted performance on the course exam covering all twelve lectures, although not the test on just the eighth lecture. These results are consistent with the hypothesis that the ability to hold and organize information plays a critical role in taking lecture notes, and are at least somewhat supportive of the idea that note-taking ability predicts retention of lecture information.

Kiewra and Benton (1988) used a somewhat similar design, the major difference being that this time the word-reordering task was used as a working memory measure. The results of this study were similar to those previously reported by Kiewra et al. (1987). More specifically, scores on the word-reordering task correlated positively with note-quantity measures, which in turn predicted performance on a course exam covering six subsequent lectures. Unlike in their previous study, note-quantity also predicted performance on a lecture-specific test, although in this case students got their notes back and studied them immediately before the test. Finally, McIntyre (1992) administered both the sentence-reordering and word-reordering tasks to students in an Introductory Psychology course, and reported that a composite score on the two tasks predicted note-taking effectiveness, a note-quantity measure calculated based on the numbers of main idea units and details in lecture notes. Note-taking effectiveness, in turn, predicted performance on a lecture-specific test as well as on the course midterm.

Taken together, these three studies demonstrate that the ability to manipulate information is an important factor in individual differences in effective note-taking, as reflected in various measures of note-quantity. It should be noted, however, that the processing tasks involved reorganizing information that was visible to the participants, rather than information in working memory, and the extent to which scores on the word- and sentence-reordering tasks correlate with other measures of working memory is unknown. That said, the word- and sentence-reordering tasks are important in part because they highlight a cognitive function that has received relatively little attention in the cognitive literature despite the fact that the generally accepted definition of working memory includes not just the ability to store information temporarily, but also the ability to manipulate information. In fact, one of the reasons why temporary storage is believed to be important for higher cognitive functions is because it makes such manipulation possible (Baddeley, 1986, 2007).

4.3. Storage while processing

In addition to storage and manipulation, working memory has been hypothesized to involve a number of executive functions, including attentional control, task switching, and multi-tasking. Therefore, it is important to explore the relationship between working memory and note-taking using working memory tasks that tap these functions. One such family of working memory tasks are what Engle et al. (1999) termed complex span tasks (e.g., reading span, counting span, operation span) in order to distinguish them from simple span tasks (e.g., digit span, word span) that only assess temporary storage. The defining characteristic of complex span tasks is that the presentation of to-be-remembered items alternates with the processing of information that is irrelevant to the memory task. In the original form of the reading span task, for example, an individual reads a series of sentences but only needs to remember the final word of each sentence (Daneman & Carpenter, 1980).

Cohn, Cohn, and Bradley (1995) were the first to include complex span tasks in a study of the relationships among working memory, lecture note-taking, and learning. Working memory was measured by two different complex span tasks (reading span and operation span), as well as a simple span task (word span). Students took notes on a lecture on economic principles, after which they completed a multiple-choice test. Data were analyzed using multiple regression models in which in addition to working memory, student attributes such as GPA and SAT scores were predictors. Although a composite score on the three memory span tasks was a significant predictor of test performance, working memory did not predict note-quantity when student attributes were statistically controlled. The zero-order correlation between working memory and note-quantity was not reported.

The Cohn et al. (1995) findings are hard to interpret because of the student attributes being controlled for in the multiple regression analyses. One of them, SAT score, is itself known to be correlated with working memory (e.g., Engle et al., 1999), a finding that Engle et al. interpreted as indicating that working memory ability was a major determinant of performance on the SAT. With regards to GPA, another student attribute controlled for in Cohn et al.’s analyses, working memory ability is also believed to play a causal role in educational attainment (Alloway & Alloway, 2010; St Clair-Thompson & Gathercole, 2006). Because differences in SAT and GPA are most likely to be the effects rather than the causes of differences in working memory, the finding that controlling for these attributes eliminated the significant relationship between working memory and note-taking sheds little light on the mechanism underlying the relationship between working memory and note-taking.

Unlike Cohn et al. (1995), Hadwin et al. (1999) reported the direct relationship between working memory and note quality as well on the effect of statistically controlling for other individual difference measures. In the Hadwin et al. study, participants took notes on a lecture on theories of evolution and DNA research. Working memory ability was measured by a reading span task and note content was assessed using a measure that gave more weight to higher-level information than to lower-level information. Working memory ability, as measured by a reading span task, predicted participants’ note content. Although this relationship was weakened when verbal ability and prior knowledge were included in the regression model, the interpretation of this finding, like the interpretation of the Cohn et al. results, is clouded by the fact...
that the variables being controlled for are more likely to be consequences than causes of individual differences in working memory.

In an important series of studies, Peverly and his colleagues (Peverly, Garner, & Vekaria, 2014; Peverly et al., 2007, 2013) explored the relationships among lecture note-taking, handwriting speed, working memory, and other variables. Handwriting speed was a consistent predictor of note quality, a finding that Peverly and colleagues interpreted as reflecting an important role for individual differences in the speed of accessing verbal codes. The relationship between working memory, as measured by the listening span task, an auditory version of the reading span task (Daneman & Carpenter, 1980), and note quality, as measured by how much participants elaborated on the idea units in their notes, was inconsistent when group administration of the working memory task was used (Peverly et al., 2007, 2013). In Peverly et al.’s (2014) most recent study, however, where the working memory task was administered individually, working memory was a significant predictor of note quality. The zero-order correlations of note quality with handwriting speed and sustained attention (as measured by the Lottery subtest of the Test of Everyday Attention; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994) were significant, but note quality was not correlated with executive attention (as measured by the Stroop task).

When Peverly et al. (2014) used hierarchical regression to analyze their results, note quality was the only significant predictor of test performance. In interpreting these results, Peverly et al. noted similarities to cognitive cascade models relating developmental changes in processing speed to changes in working memory (Fry & Hale, 1996; Kail & Salthouse, 1994). Indeed, it would appear that their data would be well described by a cascade model in which taken together with greater sustained attention leads to better lecture note-taking, and thereby to better test performance.

It should be noted that the studies reviewed so far all examined the taking of handwritten notes, yet Peverly et al. (2014) reported that 50% of the respondents in an ongoing survey from their laboratory of undergraduates from different universities indicated that they take lecture notes with a laptop computer. In the one study to examine the role of working memory in note-taking using computers, Bui et al. (2013) found that working memory, assessed with a reading span task, predicted note-quality when participants were instructed to take organized notes. Working memory did not predict note-quantity, however, when participants were instructed to try and transcribe the lecture by recording everything the lecturer said. Interestingly, working memory predicted delayed test performance regardless of the note-taking strategy that was used, but when the testing was immediate, working memory predicted test performance only for those who took organized notes. These findings, which are discussed in greater detail below, suggest that finer-grained analyses based on differences between samples (Peverly et al., 2007) and note-taking modalities and strategies (Bui et al., 2013), among other factors, are needed to determine under what conditions working memory ability predicts note-taking and test performance, and under what conditions it does not. Accordingly, we next consider various factors that may modulate the relationships among these variables.

5. Factors affecting the role of working memory

To briefly summarize the findings reviewed so far, positive relationships among working memory abilities, lecture note-taking, and test performance have been found when working memory is measured using both short-term memory tasks and complex span tasks, as well as when it is measured using information-processing tasks that require reorganizing information. These different types of tasks may measure different working memory abilities, however, and evidence is emerging that the strategies students use in lecture note-taking may affect whether working memory predicts note-taking and test performance (Bui et al., 2013). It is likely that other factors are involved as well, at least some of which are more or less under the control of instructors (e.g., lecture pace and length). Finally, technological innovations may be in the process of altering the relationships among working memory, note-taking, and learning, even as researchers and educators try to understand them.

5.1. Working memory tasks

Whether or not a relationship is observed between working memory and note-taking ability appears to be partly determined by exactly what tasks are used to assess working memory ability and how they are administered. Significant correlations between working memory and note-taking have been found consistently when working memory is assessed using tasks that require participants to reorganize information (Kiewra & Benton, 1988; Kiewra et al., 1987; McIntyre, 1992). Mixed results have been obtained with group-administration of complex span tasks (Peverly et al., 2007, 2013). However, significant correlations have been reported more consistently when complex span tasks are individually administered (Bui et al., 2013; Hadwin et al., 1999; Peverly et al., 2014), although as discussed in the following section, note-taking strategy may also play a role (Bui et al., 2013).

Complex span tasks (e.g., reading span) have been the most frequently used measures of working memory in studies of individual differences in cognitive ability (Conway et al., 2005), whereas information-processing tasks (e.g., word and sentence reordering) like those used by Kiewra and others (Kiewra & Benton, 1988; Kiewra et al., 1987; McIntyre, 1992) that focus on the ability to reorganize information have rarely been used, despite the fact that according to Baddeley (1986, 2007), manipulating information is one of the defining characteristics of working memory. Although the word- and sentence-reordering tasks do assess the relatively neglected manipulation aspect of working memory, the storage aspect of these tasks is minimal because the items to be reordered remain visible. In contrast, complex span tasks depend partly on storage capacity, but they are defined by the need to multi-task, maintaining information while alternating between processing incoming information and performing an irrelevant secondary task. Indeed, it is this multi-tasking aspect, with its dependence on executive processes, which has often been assumed to underlie the relationship between working memory and fluid intelligence (e.g., Engle et al., 1999), although researchers’ views on this point may be changing (e.g., Colom et al., 2006; Friedman et al., 2006; Redick & Lindsey, 2013; Unsworth & Engle, 2007a).

Surprisingly little is known about the role of storage capacity in note-taking. The Brown–Peterson task used by DiVesta and Gray (1973) assesses forgetting, not storage, although they described it as a memory span measure. In fact, simple span tasks that focus on temporary storage (e.g., digit span, word span) have hardly been used in research on note-taking. The one case that we know of is the word span task in Cohn et al. (1995), but they also administered two complex span tasks and did not report correlations for the three span tasks separately. To the best of our knowledge, only two tasks have been devised that attempt to assess both the storage and manipulation aspects of working memory, the alphabet span task (Craik, 1986) and the letter-number sequencing task (Wechsler Adult Intelligence Scale, WAIS-IV; Wechsler, 2008), neither of which has been used in research on lecture note-taking. Studies that assess the combined contributions of temporary storage and manipulation to note-taking or that compare their contributions could potentially shed considerable light on the bases for individual differences in note-taking ability, as might studies that compare the contributions of the storage and executive, multi-tasking aspects of complex span tasks.

One of the reasons that the working memory construct has largely replaced the short-term memory construct in contemporary cognitive psychology is because of the richness of the former construct, which subsumes the storage function of short-term memory and adds additional components to form a working memory system. Previous studies (Kiewra & Benton, 1988; Kiewra et al., 1987; McIntyre, 1992) clearly establish the ability to manipulate information as an important
determinant of individual differences in note-taking, but future research would do well to examine the roles that all of the various component abilities, separately and in combination, play in note-taking as part of the effort to understand the relationship between individual differences in working memory abilities and academic performance.

5.2. Note-taking strategy

For the most part, researchers examining the relationship between working memory and note-taking have not instructed their participants on how to take their notes. Indeed, relatively few students ever receive formal instruction in note-taking. Perhaps as a result, different students may use different note-taking strategies, and students may alter the strategy they use from one course or lecture situation to the next (Piolat, Olive, & Kellogg, 2005; Van Meter et al., 1994). Moreover, note-taking strategies may differ in their reliance on working memory (Bui et al., 2013), and thus variability in note-taking strategies can potentially mask a correlation between working memory and note-taking that would have been observed if all participants had used strategies that are dependent on working memory.

For example, consider the results for those who used a computer to take notes in the study by Bui et al. (2013) discussed previously. Half of these participants were told to try and transcribe the lecture, recording everything that the lecturer said, and the other half were told to organize their notes, paraphrasing what was said. As mentioned previously, when participants in the Bui et al. study were told to organize their notes, working memory ability was a significant predictor of note-taking. From the standpoint of understanding the role of note-taking strategies, however, what is important is that this was only true when participants took organized notes, paraphrasing what was said. As mentioned previously, when participants in the Bui et al. study were told to organize their notes, working memory ability was a significant predictor of note-taking. These results suggest that the specific note-taking strategies that students use can dictate whether or not working memory ability will play a mediating role in note-taking performance. These strategies may vary not only across individuals, but also across samples and situations (for a review, see Piolat et al., 2005), complicating efforts to understand the relationship between working memory and lecture note-taking.

According to Piolat et al. (2005), different note-taking strategies place differential demands on executive and/or attentional processes like those involved in working memory tasks. Much of the evidence for this view comes from studies using a dual-task paradigm. As may be seen in Fig. 1, participants are much faster to respond to a tone while simply reading or copying text than when they are composing, revising, or translating text. Piolat et al. hypothesized that this is because tasks like composing and translating require much more cognitive effort, in that they place a much greater demand on executive/attentional resources than merely reading or copying. Similarly, they argue that lecture note-taking takes much more cognitive effort than merely copying text, and nearly as much as composing or translating text, again as evidenced by a comparison of response times. Response times to a tone are also longer when taking lecture notes than when taking notes while reading, which may be attributed to the severe time pressure involved in not falling behind the lecturer.

In addition, Piolat et al. (2005) argued that these long response times reflect the fact that note-taking is typically not the simple transcription of information that is heard or read, but rather is a much more complicated process that depends heavily on the executive functions involved in managing multiple cognitive processes concurrently (Engle et al., 1999). They suggested further that the specific strategy used in a particular situation probably depends on the skills and abilities of the note-taker. Simply transcribing information might seem to be a suboptimal strategy, particularly from a depth-of-processing perspective (Craik & Tulving, 1975; Kiewra, 1985); yet it is reported to be common under certain circumstances (Van Meter et al., 1994). Moreover, as we shall show in the next section, simple transcription can lead to greater note-quantity and better test performance than organized note-taking when students are using computers (Bui et al., 2013). Indeed, it is likely that no single note-taking strategy is best for all students or all situations. As a result, it may be important to expose students to a variety of note-taking strategies in order to allow them to make informed decisions as to which strategies work best for them and when.

5.3. Lecture pace

Although students can choose which note-taking strategy to use, one factor in lectures that they usually are unable to control is the speed at which the instructor lectures. Little work has been directed towards understanding how lecture pace affects students’ retention of lecture information when taking notes, which is surprising given that pace should directly impact the amount of information that students are able to record. Students often report that rapidly delivered lectures prevent them from using their preferred methods of note-taking (e.g., Van Meter et al., 1994). As Piolat et al. (2005) pointed out, the average speaking rate exceeds the average writing rate, and those students who are already having difficulty trying to take notes when lectures are delivered at an average speaking rate would be at an even greater disadvantage in faster paced lectures.

The first study to explore the effects of lecture pace was Peters (1972), who had participants either listen to a normally paced lecture (146 words per minute) or a fast paced lecture (202 words per minute). Peters failed to find an overall effect of lecture pace on test performance, but for individuals who scored low on listening efficiency (measured as recall of a list of definitions), performance on a multiple-choice test was better when they were not required to take notes, or when they took notes and the lecture pace was normal, than when they tried to take notes on a lecture delivered at a fast pace. These results suggest that individual differences in a student’s listening ability interact with the rate of a lecture’s presentation in determining whether note-taking provides either a benefit or detriment to performance on a test of comprehension of the lecture material.

The effect of lecture pace on note-taking was also examined by Aiken et al. (1975). The lecture was divided into four segments with breaks in between the segments, and in addition to pace, Aiken et al. also varied whether participants took notes while listening to the lecture or during the breaks. Test performance was better when the speech rate was normal than when it was fast. Interestingly, test performance was best for participants who took their notes during the breaks and immediately following the lecture, compared to those who took their notes while listening to the lecture. Allowing breaks for note-taking effectively diminishes the divided attention and multi-tasking demands of traditional note-taking, and may thus weaken the relationship between note-taking and working memory ability, at least as assessed by complex span tasks.

To the best of our knowledge, no studies have followed up on the findings by Peters (1972) and Aiken et al. (1975) regarding the interaction of lecture pace and individual differences in ability, although Ruhl...
and Suritsky (1995) have successfully used pauses to enhance lecture note-taking by learning disabled college students. Salthouse (1996) proposed two mechanisms to explain the well-established relationships among individual differences in processing speed, working memory and higher order cognition, and his processing speed theory would appear to be directly applicable to note-taking. His limited time mechanism, which operates exactly as the name suggests, captures the deleterious effects of rapid lecture pace and predicts that slower processors will be particularly affected. This prediction is supported by the consistent finding that the difference between young and older adults’ immediate recall of spoken words and sentences increases as a function of speech rate: Older adults, who are much slower processors, show much larger decreases in recall than young adults, and this is exacerbated by increases in sentence complexity (e.g., Wingfield, Peele, & Grossman, 2003; Wingfield, Poon, Lomabardi, & Lowe, 1985). Similarly, one would expect that increases in lecture pace and the difficulty of the material would have more adverse effects on immediate recall and note-taking by slower young adults.

Salthouse (1996) also postulated a simultaneity mechanism that captures the interaction between processing speed and forgetting rate: The longer it takes one to perform task, the longer one has to remember the information required by that task. Thus, for example, slower individuals attempting to take organized notes are more likely to forget some of the information they are trying to organize than faster individuals. It may be noted that both the limited time and simultaneity mechanisms operate here, so that slower processors are doubly vulnerable. It should be pointed out that in the case of note-taking, Salthouse’s theory predicts that being physically slow at recording information can be just as deleterious as being mentally slow to process it. This, in turn, suggests that an intervention that speeds up the process of recording information could have much the same benefit as becoming a faster information processor. Fortunately, it may be much easier and more practical to speed up recording than processing, which brings us to the topic of note-taking with computers.

5.4. Note-taking modality

The first researchers to study lecture note-taking probably could not have envisioned a classroom where note-taking would be done using computers. However, rapid advancements in technology have resulted in computers increasingly being incorporated into students’ classroom learning experiences. Furthermore, the combination of the portability and flexibility of laptop and tablet computers has resulted in a steady increase not only in the percentage of college students who own a computer (Smith & Caruso, 2010), but also in students’ preference for taking notes using their computers (Eflaw, Hampton, Martinez, & Smith, 2004). In addition to the convenience that computers provide, taking notes with a computer may also increase transcription speed during lecture note-taking because typing is typically faster than handwriting (e.g., Horne, Ferrier, Singleton, & Read, 2011; Rogers & Case-Smith, 2002). As a result of the increase in transcription speed that is possible, using computers may offer students the opportunity to take more lecture notes, and given that note-quantity is a good predictor of test performance (e.g., Bui et al., 2013; Kiewra & Benton, 1988; Kiewra et al., 1995), computer note-taking may result in better scores on tests that assess memory for lecture material.

It should also be pointed out that the role of working memory in lecture note-taking may differ depending on whether the notes are handwritten or typed into a computer. Olive and Poliat (2002) have argued that handwriting places extra cognitive demands on note-takers because they not only have to execute the motor movements needed to write down information, but they also have to monitor the spatial position of their hands in order to make sure that the letters and words will be appropriately spaced and that the next words will fit on the current line, all while keeping track of what the lecturer is currently saying. In contrast, taking notes with a computer eliminates some of these cognitive demands because word processors automatically maintain consistent spatial alignment.

Bui et al. (2013) had participants either take notes with a pencil or pen and type them into a computer. As may be seen in Fig. 2, using a computer resulted in participants including a larger proportion of the idea units from the lecture in their notes, particularly when they were using a transcription strategy (i.e., trying to record everything that was said) rather than following the more traditional practice of taking organized notes. Notably, the greater note quantity observed when participants used a computer was not simply the result of their including more unimportant details. Their notes also contained more important details, and because note quantity is a means and not an end in itself, it should be pointed out that the computer users also recalled more important details on a subsequent test than those who took notes by hand.

Although note-taking strategy had no effect on either the note-quantity or test performance of those who took notes by hand, for participants who took notes with a computer, using the transcription strategy resulted in their both recording more ideas units in their notes and recalling more idea units later. This interaction between note-taking strategy and modality may be clearly seen in Fig. 2, and it illustrates what may become a significant issue in note-taking research: The factors affecting note-taking and its relation to test performance may be different depending on whether notes are taken by hand or with a computer.

Further, the Bui et al. (2013) findings suggest that when the computer’s potential for increasing note-quantity is realized, as when students use a transcription strategy, it may change the effects of other important factors. For example, when there was no opportunity...
for studying one’s notes, those who took organized notes showed much less forgetting over a 24-h delay than those using a transcription strategy; if participants had an opportunity to study their notes, however, then those who used a transcription strategy benefited greatly from this opportunity whereas those who took organized notes did not. In fact, transcribing one’s notes and then going over them immediately after the lecture resulted in much better performance on a delayed test than taking and studying organized notes. These findings may legitimize a much maligned note-taking strategy, but they also provide further support for the idea, suggested above, that findings from handwritten note-taking may not necessarily generalize to note-taking with computers.

In the Bui et al. (2013) study, this may be seen in the fact that the transcription strategy produces qualitatively as well as quantitatively different effects on note-taking depending on whether notes are taken by hand or by computer (see Table 1). Whereas transcribed notes had the same total number of idea units as organized notes when notes were taken by hand, they had more unimportant details but fewer main ideas and less important details, just as proponents of organized note-taking might have predicted. When a computer was used, however, taking transcribed notes increased the total number of idea units without sacrificing either the number of main ideas or important details.

For the current effort, we revisited the data from the Bui et al. (2013) study, combining the data from all of the participants who took notes using a computer. This effort yielded a total of 76 participants across all three experiments who tried to transcribe the lecture and 76 who took organized notes. As may be seen in Fig. 3, low span individuals (i.e., those whose scores on a reading span task were in the bottom quartile) who used a transcription strategy not only had as many idea units in their notes, on average, as high span individuals (i.e., those whose scores were in the top quartile) using the same strategy, they also had significantly more idea units in their notes than high span individuals who took organized notes (43% vs. 36%).

The conditions under which the transcription strategy leads to better test performance remain to be determined: It does lead to better test performance when notes are taken with a computer but not when they are handwritten, and it leads to better test performance when the test is given immediately after the lecture but not when the test is delayed unless students are given the opportunity to study their notes (Bui et al., 2013). Clearly, the constraints on the transcription strategy need to be determined before recommending its general use by students who do not have good working memory ability. Nevertheless, what does seem clear is that questions concerning working memory, note-taking strategies, and learning may have different answers depending on the note-taking modality involved.

Computers have the potential to serve as powerful tools for helping students take lecture notes, and take more of them, which in turn can improve their test performance. Importantly, students are now given a means by which they can take notes while relying less on cognitive abilities (e.g., working memory) that otherwise are critical for carrying out this task. Put another way, computers may help students offload some of the cognitive demands present in lecture note-taking. For those who are strong in the cognitive abilities on which note-taking traditionally relies, this may not make much of a difference, but for those who are average or below-average, this use of computers may help level the educational playing field.

The expanded role of computers in education will likely have a variety of consequences. For example, a recent study by Barrett et al. (2014) raises the possibility that students who take lecture notes using a computer do better on exams if they can respond to questions on their computers than if they have to write their answers by hand. Although the Barrett et al. study was a small one, their results are consistent with the principle of encoding specificity (Tulving & Thomson, 1973), and are an important reminder of the sometimes unintended results of technological innovation.

Finally, the results of the Bui et al. (2013) study highlight the importance of studying note quality as well as note quantity: Note-taking modality (i.e., using a computer versus taking notes by hand) interacted with strategy to produce qualitatively different effects on note contents. Measuring qualitative differences in note-taking benefits from careful analysis of lecture contents as well as note contents, and Bui et al. were fortunate to be able to use a text previously analyzed by Rawson and Kintsch (2005) in terms of main ideas and both important and unimportant details, just as Peverly and his colleagues (e.g., Peverly et al., 2007) based their analyses of note quality on a lecture previously analyzed by Brobst (1996). Future research on note-taking will likely need to compare handwritten notes with those taking with a variety of digital instruments, including tablets and laptops as well as other devices (e.g., wearable devices) that are only beginning to appear. We expect that the potential benefits of analyzing qualitative differences in the contents of individuals’ notes will outweigh the effort that will be required in conducting careful, qualitative analyses of the contents of both lectures and notes on topics taken from many different disciplines.

6. Concluding remarks

The notion that working memory ability is important for lecture note-taking has been around since at least the 1970s (e.g., Divesta & Gray, 1973). After all, note-taking involves recording (writing or typing) either a verbatim or transformed (e.g., summarized) version of what has just been said, all the while continuing to process and maintain the information that is currently being said. This, of course, is exactly the kind of function that Baddeley (1986) envisioned when he described working memory as a system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks, because note-taking, especially taking organized notes, is definitely a complex cognitive task.

Despite the intuitive appeal of this idea, however, studies of the relationship between working memory, note-taking, and test performance

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Table 1
Proportion of idea units in notes (standard deviations in parentheses) in Exp. 1 of Bui et al. (2013).

<table>
<thead>
<tr>
<th>Group</th>
<th>Overall</th>
<th>Main Details</th>
<th>Important Details</th>
<th>Unimportant Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand</td>
<td>.28 (.12)</td>
<td>.54 (.15)</td>
<td>.41 (.08)</td>
<td>.20 (.16)</td>
</tr>
<tr>
<td>Transcribe</td>
<td>.28 (.10)</td>
<td>.46 (.16)</td>
<td>.33 (.12)</td>
<td>.24 (.12)</td>
</tr>
<tr>
<td>Computer</td>
<td>.34 (.13)</td>
<td>.50 (.16)</td>
<td>.48 (.10)</td>
<td>.26 (.17)</td>
</tr>
<tr>
<td>Transcribe</td>
<td>.44 (.12)</td>
<td>.59 (.15)</td>
<td>.53 (.13)</td>
<td>.41 (.14)</td>
</tr>
</tbody>
</table>

Note: Numbers indicate the mean proportions of the total of 125 idea units, 8 main points, 15 important details, and 16 unimportant details in the passage.
have sometimes produced what appear to be inconsistent results. As we have shown, however, some of this inconsistency may be due to lumping together zero-order correlations with multiple regression results, at least some it is likely attributable to the way in which working memory was assessed, and another portion may be attributable to variation in note-taking strategy and differences between samples. Any inconsistency, moreover, must be interpreted in the context of changing views of individual differences in working memory. Although Baddeley (1986) originally described working memory in terms of a multi-component system, until relatively recently, individual differences researchers tended to focus on just one of Baddeley’s components, the central executive, as being the essence of a unitary working memory ability (Engle et al., 1999; Kane & Engle, 2002). From this perspective, complex span tasks were seen as the way to measure this unitary construct. Subsequent research, however, has challenged this view, and there is an emerging consensus that performance of even this one type of working memory task may involve a number of abilities, and that other types of tasks may tap other abilities (e.g., Hale et al., 2011; Oberauer et al., 2003; Redick & Lindsey, 2013; Unsworth & Spillers, 2010).

Consider, for example, n-back tasks, which many cognitive neuroscientists have seen as capturing the essence of working memory, a role once played by complex span tasks for many psychologists. n-back tasks focus on the need to continually update what is temporarily being stored, something which is required in lecture note-taking although to date, such tasks have not been used in note-taking research. Perhaps surprisingly, complex span tasks and n-back tasks have turned out to be only weakly correlated (for a meta-analytic review, see Redick & Lindsey, 2013), even though both types of tasks are correlated with fluid intelligence. Moreover, most of the intelligence-related variance that each type of working memory task explains is unique (Kane, Conway, Miura, & Colflesh, 2007), and training that improves performance on one type of task results does not result in transfer to tasks of the other type (e.g., Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Lilienthal, Tamez, Shelton, Myerson, & Hale, 2013).

Because no single task captures the essence of working memory and different tasks tap different sets of working memory abilities whose contributions may vary across individuals, strategies, and situations, it is perhaps not surprising if some inconsistencies are observed. Clearly, the job of future research will be to try to discover what underlies the complex relationship between working memory and note-taking even as researchers try to understand the nature of working memory itself.

One reason why this may be important for educational purposes is that although evidence is accumulating that general working memory ability cannot be improved through training (for a recent review, see Shipstead, Redick, & Engle, 2012), certain component skills (e.g., updating) can be improved by training (e.g., Dahlin, Neely, Larsson, Bäckman, & Nyberg, 2008; Lilienthal et al., 2013). Thus, to the extent that specific weaknesses in students’ note-taking can be identified, it may be possible to use training to remediate these deficits, and a clearer understanding of the relationship between working memory and note-taking may help in identifying which skills to target. For example, as research using reordering tasks has shown, the ability to manipulate information is a key component of both working memory and taking organized notes (e.g., Kiewra & Benton, 1988; Mchtyre, 1992). If the future studies find that information-manipulation can be improved with training and that such improvements actually benefit note-taking, for example, then analogous training research with other processes common to both working memory and note-taking could follow, potentially opening up new avenues for the application of cognitive research to educational interventions.

Further, recent research suggests that the cognitive demands of note-taking may be changing alongside technological advancements, and students may need help in adapting to these new demands. For example, not only has the number of students who own portable computers increased dramatically (Smith & Caruso, 2010), but so has the proportion of students who take lecture notes using these computers (Eafw et al., 2004). Because computerized note-taking is faster than hand-writing notes, it has the potential to at least partially alleviate the cognitive demands imposed by factors such as lecture pace, but whether or not this occurs may depend on what note-taking strategies students use (Bui et al., 2013).

In addition, online learning is becoming increasingly popular even as it is changing. The first massive open online course (MOOC) was offered at the University of Minnesota in 2008 (Mackness, Mak, Fai, & Williams, 2010), and a number of major universities (including Stanford, Princeton, the University of Pennsylvania, and the University of Michigan) are partnering to offer further MOOCs (Pappano, 2012). Having access to lectures on demand may allow students to listen to a lecture in chunks, rather than all at once. This may be particularly useful in situations where note-taking is very cognitively demanding. Instead of missing important points in the lecture, students can simply pause or repeat critical lecture segments. Research that could provide instructors and students with guidance regarding optimal segment durations would be very valuable. The results of one early study suggest that taking notes during pauses between segments may be more effective than taking notes continuously (Aiken et al., 1975), perhaps because it minimizes the divided attention and multi-tasking demands associated with traditional note-taking. Such possibilities clearly seem worth exploring.

Both the ways in which information can be accessed by students and the technology available to them for recording and organizing this information are changing, and researchers and educators must consider the cognitive demands presented by these novel situations and how students with different sets of strengths and weaknesses might best cope with these demands. We believe that one way to begin is by trying to more fully understand the demands on their multiple working memory abilities when they try to record and organize information.

References


