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Is Working Memory Involved in the Transcribing and Editing of Texts?

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Generally, researchers agree that that verbal working memory plays an important role in cognitive processes involved in writing. However, there is disagreement about which cognitive processes make use of working memory. Kellogg has proposed that verbal working memory is involved in translating but not in editing or producing (i.e., typing) text. In this study, the authors used articulatory suppression, a technique that reduces working memory to explore this question. Twenty participants transcribed six texts from one computer window to another, three of the texts with articulatory suppression and three without. When participants were in the articulatory suppression condition, they transcribed significantly more slowly and made significantly more errors than they did in the control condition. Implications for Kellogg's proposal are discussed.

Keywords: *writing theory; verbal working memory; writing-process interference; language bursts; transcription*

In the past decade, substantial effort has been devoted to understanding the role of working memory[1] in writing. Kellogg (1996) and Hayes (1996) have both assigned a central role to working memory in their models of the writing process. Understanding the ways different writing processes draw on the same limited working-memory resources can help us understand why some processes are more difficult than others and how these processes may interfere with each other. For example, Chenoweth and Hayes (2001, p. 94) found that second-language learners were more skillful in editing their texts after they had composed them than while they were composing them. These researchers attributed the difference in editing skill to memory-based interference between the processes of composing and editing.

Baddeley and his colleagues (e.g., Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993) proposed a model of working memory that has received wide acceptance. The model consists of three parts: a phonological loop for storing verbal information, a visuospatial sketchpad for storing visual information, and a central executive that among other functions manages the other two parts.

The phonological loop consists of two parts. The first part, called the *phonological short-term store*, represents verbal material in a phonological (auditory) code that decays within a few seconds. The second part is a subvocal *articulatory rehearsal process* that refreshes the material in the short-term store. Engaging in articulatory rehearsal is experienced as repeating the material to be remembered to oneself. For example, if you have mentally composed a sentence and want to remember it until you can write it down, you can repeat it to yourself to keep it fresh in your memory. That is articulatory rehearsal.

It is possible to interfere with a person's articulatory rehearsal process in at least two ways: (a) by exposing the person to irrelevant speech and (b) by articulatory suppression, that is, by requiring the person to repeat a syllable again and again. Both of these methods for interfering with rehearsal were employed in a study of digit memory by Salame and Baddeley (1982). In this study, participants were shown lists of nine digits presented serially on a TV screen. Their task was to write down the digits immediately after all nine had been presented. In the irrelevant speech condition, one-syllable words or nonsense syllables were presented using a loudspeaker during the visual presentation of the numbers. Participants were instructed to ignore the auditory input and to attend only to the visually presented digits. In the articulatory suppression condition, participants were asked to repeat the syllable *the* again and again during the presentation of the digits.

Memory for digits was significantly reduced both by irrelevant speech and by articulatory suppression. However, the reduction caused by articulatory suppression was significantly greater than that caused by irrelevant speech. Furthermore, articulatory suppression and irrelevant speech together caused no more memory reduction than was caused by articulatory suppression alone. These results suggest that articulatory suppression is more effective in interfering with rehearsal than is exposure to irrelevant speech. Articulatory suppression may reduce memory for words by as much as 50% (Longoni, Richardson, & Aiello, 1993).

The researcher perhaps most responsible for promoting interest in the role of working memory in writing is Ronald Kellogg. He has carried out an extensive program of research on the cognitive resources demanded by the various cognitive processes involved in writing (Kellogg, 1988, 1990). In

Figure 1
Kellogg's (1999) Model of the Role of Working Memory in Writing

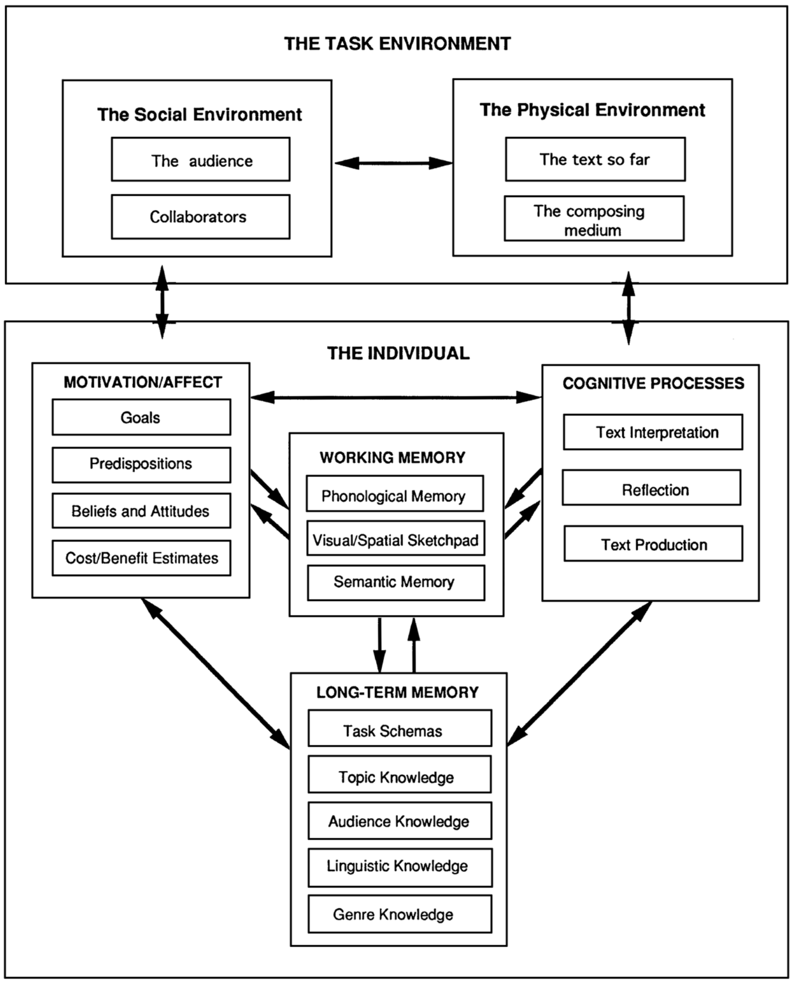
	Working Memory Component		
Basic Process	Spatial	Central Executive	Verbal
Planning	X	X	
Translating		X	X
Programming		X[a]	
Executing			
Reading		X	X
Editing	X		

Note: X indicates use of component.
a. For highly practiced motor skills, these demands are small if not negligible.

1996, Kellogg and Hayes independently proposed that working memory be included as a central component in models of writing. Kellogg's model, as slightly revised in 1999, is shown in Figure 1 and Hayes' model in Figure 2. Kellogg's model concerns the relations between working memory and cognitive process represented in Hayes' model in the middle and right of Figure 2. Although both models build on the description of working memory provided by Baddeley and his colleagues (e.g., Baddeley & Hitch, 1974; Gathercole & Baddeley, 1993), the two models differ in how the various writing processes use working memory. Hayes' model represents working memory as a resource that is available to and presumably used by all of the writing processes. In contrast, Kellogg's model, in both the 1996 and the 1999 version, makes specific predictions that particular writing processes draw on some of the components of working memory and not others. In particular, Kellogg (1999) asserts that translating and reading make use of verbal working memory but not spatial working memory. He also contends that editing[2] and planning make use of spatial working memory but not verbal working memory. Finally, he argues that programming, that is, planning for and executing motor movements (such as those used in typing or handwriting) use neither spatial nor verbal working memory.

There is strong empirical support for the prediction that verbal working memory is involved in the process of translating. Levy and Marek (1999) have shown significant decrements in a sentence-writing task in which participants were required to listen to irrelevant speech while performing the task. Chenoweth and Hayes (2003) asked adult writers to compose a sentence summarizing a wordless cartoon and found that articulatory suppres-

Figure 2
Hayes's (1996) Framework for Understanding Cognition and Affect in Writing



sion significantly slowed sentence production in this task. They also found that the pacing of the sentence-production process was changed. Ordinarily, sentences are produced in bursts. That is, the writer produces a sequence of words in rapid order, then pauses, produces another sequence, pauses, and so on. With articulatory suppression, the length of these bursts was reduced to about 60% of the length observed without articulatory suppression.

Levy and Marek (1999) also provided empirical support for other aspects of Kellogg's (1996) model. In a series of experiments, these researchers compared the performance of writers who were exposed or not exposed to irrelevant speech while performing a variety of writing tasks. In Experiment 1, Levy and Marek tested Kellogg's prediction that the processes of programming and executing motor movements do not involve verbal working memory. They asked participants to transcribe text from one computer window to another, a task that requires both programming and executing motor movements. The researchers then compared the number of words typed and the number of words typed correctly by students exposed or not exposed to irrelevant speech. Consistent with Kellogg's prediction, Levy and Marek found no significant differences between the groups on either measure.

In Experiment 2, Levy and Marek (1999) tested Kellogg's (1996) hypothesis that editing does not employ verbal working memory. They asked participants to detect spelling and grammatical errors in text and compared performance with and without irrelevant speech.[3] They found no significant difference between these conditions. These results are at variance with Chenoweth and Hayes (2003), who found that articulatory suppression led to an increase in the number of uncorrected errors in the sentences that participants produced, suggesting a decrease in the effectiveness of the editing process under articulatory suppression. The experiment, described below, is parallel to Levy and Marek's (1999) Experiment 1 on verbal working memory in transcription but uses articulatory suppression rather than irrelevant speech to interfere with verbal working memory.

Method

Participants

The participants were 20 graduate and undergraduate students at Carnegie Mellon University who responded to an advertisement for individuals who could type 40 words a minute or more in English with reasonable accuracy. Participants were paid $10 for their time.

Design

There were two conditions: the articulatory suppression condition (hereafter, AS condition) and the control condition, without articulatory suppression. Each participant transcribed text in both conditions.

Procedure

The task was to use a computer keyboard to transcribe texts from one computer window to another. The texts were taken from a nontechnical essay on wine making. In the AS condition, participants said the word *tap* aloud in time to a metronome that clicked 120 times a minute while transcribing the texts. In the control condition, they tapped a foot in time to the metronome while transcribing.[4] If a participant stopped saying *tap* or tapping a foot during transcription, the experimenter reminded him or her to do so.

Each experimental session started with two practice trials of 1 min each that were used to familiarize the participants with the transcription task and the experimental conditions. The practice sessions were followed by six test trials, each 3 min long. In each pair of test trials (that is, Trials 1 and 2, Trials 3 and 4, and Trials 5 and 6), one trial involved the experimental condition and the other, the control condition. The order of conditions within each pair of trials was randomized. Participants were told to take as much time as they liked to rest between trials.

A key-trapping program written in cT[5] was used to measure (a) the start time of each trial, (b) the time of occurrence and identity of each character typed, and (c) each deletion. In addition, the transcribed texts were scanned for errors, that is, for any deviations from the original texts. These data were used to provide measures of the following variables:

- Transcription rate (words typed per minute)
- Error rate (uncorrected errors per 100 words)
- Correction rate (corrected errors per 100 words)
- Wasted keystrokes (percentage of total keystrokes that were devoted to deleting errors and to typing the errors that were corrected)
- Number of bursts in each trial (a burst is a period of continuous typing followed by a spontaneous pause of 2 or more seconds in which no typing occurred)

Two of the first 10 participants in the study spontaneously commented that they could remember little of the material they typed during the AS condition. At this point, we modified the study design by adding a posttest to measure participants' memory for the material that they had typed. The posttest consisted of 23 five-alternative multiple-choice questions about the text. Each question was based on information available in only one of the six test passages. In all questions, the final option allowed the participant to indicate that the text did not provide the answer to the question. We administered the posttest after the participant had transcribed all of the texts. Participants were not informed beforehand that there would be a posttest. Question 1 of the posttest questionnaire was as follows:

1. In Napa, modern grape growing techniques include
   a. advanced vine treatments
   b. genetic modification of species
   c. hydroponics
   d. safe insecticides
   e. didn't say

Some participants who typed relatively slowly failed to transcribe parts of the texts on which some of the questions were based. Therefore, participants were scored only on those questions that were based on parts of the texts they had typed.

Results

We have analyzed the data in two ways for each of the dependent measures:

1. a repeated-measures analysis of variance for the first 19 participants[6]
2. a matched *t* test comparing the average across trials for the experimental and control conditions for all 20 participants

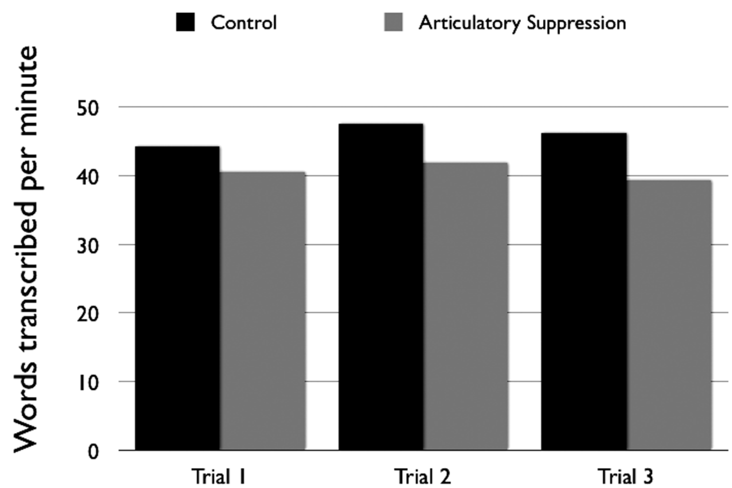
Transcription Rates (Words per Minute)

Figure 3 shows the transcription rates for each condition and each trial for 19 participants. Transcription rates were significantly higher for the control than for the AS condition ($F = 10.01$; $df = 1,18$; $p = .0054$), and there was a significant effect of trial ($F = 4.89$; $df = 2,18$; $p = .0132$). The interaction between conditions and trails was not significant. The matched *t* test analysis also showed a significant effect of condition ($t = 3.219$, $df = 19$, $p = .0045$). The mean transcription rate for 20 participants was 46.36 words per minute for the control condition and 40.36 words per minute for the AS condition.

Uncorrected Errors

Figure 4 shows the number of uncorrected errors per 100 words of transcribed text for each condition and each trial for 19 participants. There were significantly more uncorrected errors in the AS condition than in the control condition ($F = 5.036$; $df = 1,18$; $p = .0376$). There was a highly significant effect of trial ($F = 9.487$; $df = 2,18$; $p = .0005$)—errors decreased with practice—but no significant interaction between conditions and trials. The matched *t* test analysis also showed a significant effect of condition ($t = 2.23$, $df = 19$, $p = .0380$). For all 20 participants, the mean number of errors per 100

Figure 3
Transcription Rates (Words per Minute) for Each Trial in Each Condition



words was 3.75 for the control condition and 4.63 for the experimental condition.

Corrected Errors

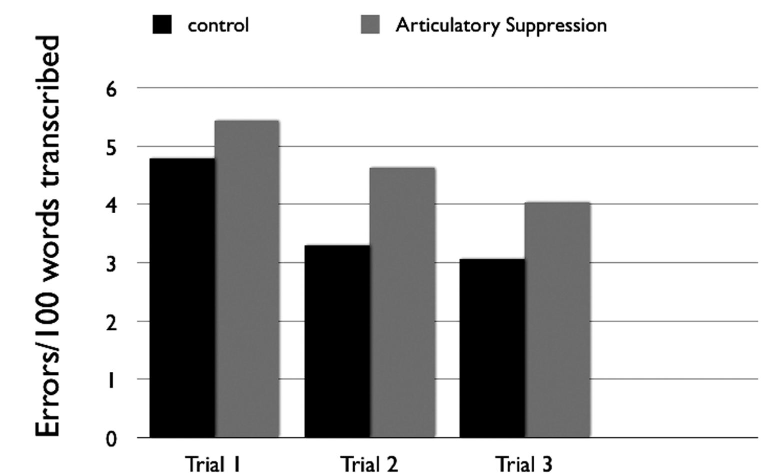
There were no significant differences between the control condition and the AS condition in the number of corrected errors revealed by either the repeated-measures analysis or the matched *t* test. The mean number of corrected errors per 100 words was 16.42 for the control condition and 14.86 for the experimental condition.

The total number of errors, that is, the number of corrected errors plus uncorrected errors, was also uninfluenced by condition, by trial number, or by the interaction of condition and trial number. The mean number of total errors per 100 words was 20.17 for the control condition and 19.49 for the experimental condition.

Percentage of Wasted Keystrokes

On average, the percentage of wasted keystrokes was smaller in the AS condition (8.8%) than in the control condition (10.5%). The difference

Figure 4
Errors per 100 Words for Each Trial in Each Condition



between conditions was marginally significant by repeated-measures analysis ($F = 4.074$, $df = 18$, $p = .0587$) and by matched t test ($t = 2.051$, $df = 19$, $p = .0542$). The effects of trial and the interaction of trial and condition were not significant.

Number of Bursts

The repeated-measures analysis revealed no significant main effects for condition or trial and no significant interaction between condition and trial. The matched *t* test analysis also showed no significant effect of condition. The number of bursts in the 3-min periods of typing was 1.77 in the control condition and 2.21 in the AS condition.

Burst Length

We did not perform statistical analyses of the burst length data, because there were too many occasions on which participants completed 3-min trials without a single 2-sec pause. Of the 120 experimental trials (six trials for each of 20 participants), 43 were completed without pause: 26 in the control condition and 17 in the AS condition.

Long-Term Memory for Materials Typed

Participants 11 through 20 correctly answered a larger percentage of questions (54.7%) in the control condition than in the AS condition (35.3%). This difference was significant by matched *t* test ($t = 2.552$, $df = 9$, $p = .0311$).

Discussion

Typing and Error Rates

The primary result of this study is that articulatory interference caused a significant reduction in typing rate and a significant increase in the number of uncorrected errors. These results contrast with those of Levy and Marek (1999), who found that irrelevant speech had no effect on either typing rate or errors. One might speculate that the difference between the two studies might be caused by a difference in the typing skill of the two groups of participants. If participants in the Levy and Marek study were more skilled typists than those in our study, we would expect them to require less working memory for typing than our participants. However, to judge by average typing speed (26 words per minute in the Levy and Marek study vs. 46 words per minute in our study), it would appear that our participants were actually the more skilled. We believe that the differences between the two studies are primarily because of differences in the method used for interfering with the rehearsal of materials in memory. As noted above, Salame and Baddeley (1982) found that articulatory suppression was substantially more effective in interfering with rehearsal than was exposure to irrelevant speech.

One could imagine that the reduced transcription rates observed in the AS condition might result not from a reduction in typing speed but from an increase in the number of errors that occurred during transcription. An increase in errors could lead to an increased amount of correcting activity (wasted keystrokes) that in turn could reduce the transcription rate. To test this hypothesis, we measured both the numbers of errors corrected and the numbers of wasted keystrokes in both the articulatory suppression and the control conditions. Although participants had significantly more errors per 100 words in their finished texts in the AS condition (4.63) than in the control condition (3.75), they did not correct significantly more errors or waste significantly more keystrokes in the AS condition than in the control condition. In fact, the numbers of errors corrected per 100 words in the control condition (16.42) was slightly greater than in the AS condition (14.86). Furthermore, the percentage of wasted strokes in the control condition (10.5%) was also greater than in the AS condition (8.8%).

Thus, participants did not commit more total errors or engage in more correcting activities in the AS condition than they did in the control condition. It appears then that the reduced typing rate in the AS condition was not an indirect effect of an increase in the error rate or of an increase in the amount of correcting activity.

Bursts

A number of studies (Chenoweth & Hayes, 2001, 2003; Friedlander, 1989; Kaufer, Hayes, & Flower, 1986) have reported that texts are produced in bursts averaging 6 to 12 words in length. Average burst length has been shown to depend on linguistic experience (Chenoweth & Hayes, 2001; Friedlander, 1989) and working-memory capacity (Chenoweth & Hayes, 2003). Chenoweth and Hayes (2003) claim that bursts occur because of the limited capacity of the translation process to convert ideas into language. However, if bursts were to be observed in our transcription task, which does not involve such conversion, this would call Chenoweth and Hayes's claim into question.

The bursting phenomenon was essentially absent in this study. Pauses were relatively rare. In a third of the trials, participants typed for 3 min without pausing, producing from 120 to 150 words in that time. Furthermore, the number of bursts was not significantly influenced by articulatory suppression. This result suggests that bursting is not associated with the tasks that the participants in this study performed, that is, transcription and local editing. Rather, we believe that bursting happens only when the writer is producing new language either through invention (as in Chenoweth & Hayes, 2003) or through revision (Hayes & Chenoweth, 2005).

Theoretical Implications of These Results for Kellogg's Model

Levy and Marek's (1999) failure to find an effect of irrelevant speech on transcription and editing was reasonably interpreted by them as evidence that immediate memory was not involved in the processes of either text production (execution) or editing and that these results supported Kellogg's (1996) model, which holds that working memory is not involved in execution and editing. Although our results clearly do not confirm those of Levy and Marek, they are not necessarily inconsistent with Kellogg's model. The transcription task used in this study and in the Levy and Marek study can be thought of as involving at least three component processes: reading, programming, and executing, that is, typing. Our results would be consistent with Kellogg's model if it could be shown that the effects of articulatory interference were confined to the reading components of the task. One way to explore this possibility might be to study the effects of articulatory interference on the transcription of memorized texts. Because this transcription task does not involve reading, an effect of articulatory interference on transcription time could not be interpreted as interference with reading.

The editing activities that occurred during our study can also be thought of as involving a component of reading. Chenoweth and Hayes (2003) found that when participants could not see the texts that they were typing, the amount of editing was substantially reduced. However, it was not completely eliminated. Thus, reading the text they had typed was clearly an important trigger to editing but not the only trigger. It is a fairly common experience to think of a sentence and then edit it before it is written down. Thus, although most editing does involve reading, as in editing someone else's text, it is conceptually possible to separate the two. Perhaps a partial replication of the Chenoweth and Hayes study that focused on the effects of articulatory interference on editing that occurs when participants cannot see their texts could shed light on this question.

At present, there is little evidence to help us evaluate Kellogg's (1996) claim that editing and production processes do not draw on working-memory resources. However, we have suggested two studies that could provide evidence to help assess these claims. At present, Hayes's (1996) model appears to accommodate the empirical evidence about the relation of editing and transcription more comfortably than does Kellogg's (1996, 1999) model.

Summary

Levy and Marek (1999) interfered with working memory by subjecting participants to irrelevant speech while they carried out a transcription task and found that it had no effect on typing rate or errors. They concluded that their results supported Kellogg's (1996) hypothesis that verbal working memory does not play a role in programming and executing motor movements (e.g., typing) or in editing. In this study, we interfered with verbal working memory by subjecting participants to articulatory interference while they transcribed texts. In contrast to Levy and Marek, we found that typing rate was significantly reduced and that the number of errors significantly increased. It appears that working memory is involved in transcription and editing. We believe that the results of these two studies differ because working memory is more severely disrupted by articulatory interference than by exposure to irrelevant speech.

The results of this study are not strictly inconsistent with Kellogg's (1996) hypotheses, because the tasks of transcription and editing used in our study and in that of Levy and Marek (1999) involved a component of reading. Further research would be needed to evaluate these hypotheses.

Language bursts were not evident during the transcription task. This supports our hypothesis that bursts occur only when language is being generated or revised.

We also found that articulatory interference reduces long-term memory for the transcribed material. This suggests that working memory is involved in the formation of long-term memories, that is, in learning.

We believe that identifying the role of working memory in the various writing processes is important for a number of reasons. It can help us to understand interference among memory processes that contend for the same scarce memory resources. Understanding interference among writing processes may cast light on writing development. For example, young writers may have to devote large amounts of working memory to the control of lower-level processes, such as handwriting or typing, and thus have little left for higher-level processes. Indeed, the development of skill in writing may require the automatization of lower-level skills so that they use less of the available working-memory resources. Furthermore, the way the student chooses to assign working memory to the various writing processes may influence writing outcomes. For example, a student who devotes too much working memory to avoiding surface errors may have too little to devote to planning. Students with smaller working-memory capacities may require different writing strategies and different teaching methods than students with larger capacities. Finally, understanding the role of working memory may help us to understand the impact of alternative writing strategies, such as free writing (Elbow, 1973), on writing performance.

There is still a great deal to be learned about the role of working memory in writing. Much research is needed. We have just completed a study on verbal working memory in revision (Hayes & Chenoweth, 2005) and are designing a new study to identify how skilled writers distribute time and verbal working-memory resources to various writing processes while performing a sentence-writing task.

Notes

1. Psychologists introduced the concept of working memory to describe the temporary storage of information necessary for carrying out tasks such as multiplying multidigit numbers without the aid of pencil and paper. In contrast to long-term memory, which can store virtually unlim-

ited amounts of material for many years, working memory is limited in the amount of material it can hold (a few items) and in the length of time it can hold it (a few seconds).

2. Here, editing means detecting spelling and grammatical errors.

3. Levy and Marek (1999, p. 30) noted that although their editing task involved reading, the more demanding part of the task was identifying and classifying errors. However, if Kellogg's (1996, 1999) model were correct, reading would be the part of the task that demanded the most working memory.

4. We did not include a control condition in which participants neither tapped their foot nor said *tap* because Chenoweth and Hayes (2003) ran this control and found no difference between it and the foot-tapping control in any of their dependent measures.

5. cT is a programming language developed at Carnegie Mellon University by David Anderson, Bruce Sherwood, Judith Sherwood, and Kevin Whitley.

6. Because of a computer error, we lost the data for the first trial of the articulatory suppression condition for Participant 20.

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