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The "R" that psychology forgot: Research on writing processes

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Development of theory and methodology related to the psychology of reading and mathematical problem solving has far outpaced progress in the realm of the psychology of writing. However, recently published theories may serve to link written language production research with mainstream psychology, and new computer-based methodologies may help to make conducting research in writing more tractable. This paper describes several new initiatives for studying writing within a framework based on recent theories of working memory.

Previous Presidential Addresses to the Society for Computers in Psychology have usually taken one of three broad approaches: (1) depict the state of the art involving the range of uses of computers in college classrooms; (2) engage in long-range forecasting regarding the possible uses of computers n years hence; (3) describe a research area in psychology that makes heavy use of computers, but is not one with which most persons would have great familiarity. The present address falls into the last of these three.

Let me begin by explaining my title. The "R" that seems to have been largely overlooked as a research topic by psychologists is the second R in the phrase *readin', ritin', and 'rithmetic*, coined years ago by someone who clearly could not spell very well. Writing is very important to academics. It is largely because of our written work that we are promoted, tenured, funded and otherwise recognized professionally. But it seems that writing as the subject of research has been overlooked by psychologists. Consider that during the last 30 years there have been over 44,000 publications in the psychological literature focusing on memory processes. During this same period, more than 31,000 contributions dealing with reading and about 14,000 examining mathematics and arithmetic have been published. In sharp contrast, only 1,050 scholarly contributions have appeared that focus on writing processes.¹ Although every major general psychology textbook contains a discussion of read-

ing processes, and most offer a treatment of mathematical problem solving, none has even an index entry for writing. Of the dozen current cognitive psychology textbooks, only two (Haberlandt, 1994; Kellogg, 1995) have even a cursory treatment of research in written language production.

There are at least two good reasons why writing-process research has been largely ignored by psychologists. First, we simply have not had much in the way of theory to motivate or guide research programs. Theories of speech production, text processing, and memory, among others, have nothing explicit to say regarding writing processes. Second, progress has been impeded by the lack of technologies and methodologies for conveniently capturing and archiving writing as it unfolds. Until recently, the most elegant tool available to writing researchers was the concurrent verbal protocol (see Hayes & Flower, 1980) generated by people as they compose text. The purpose of the present paper is to bring to the forefront recent methodological and theoretical approaches that make the study of writing more tractable than it was only a few years ago.

New Approaches to Studying Writing

Figure 1 shows a representative experimental setup used in much of my research with my long-time collaborator, Sarah Ransdell, and two graduate students, Pamela Marek and Joseph Lea (e.g., Lea & Levy, 1996; Levy & Ransdell, 1995, 1996; Marek & Levy, 1996). The usual desktop computer is shown in the middle. At the top left is an inexpensive, off-the-shelf box that transforms the VGA output to a broadcast-quality video signal. This enables the unobtrusive archiving on videotape or CD-ROM copies of the images that appear on the writer's screen as the text unfolds. The microphone at the bottom of the illustration can be used to record a writer's

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Figure 1. A typical experimental setup.

concurrent verbal protocol. Some projects need writers to perform a secondary task that requires an overt response, such as responding as quickly as possible to an aperiodically presented tone. When the writer's hands are occupied using the keyboard and mouse, and the microphone is capturing the writer's verbal protocols, we connect a footswitch on the floor to the computer to collect secondary-task reaction times (RTs).

Behind the scenes are two important pieces of software. The first is a program that stores every keystroke and the time at which it occurs, facilitating the processing of data for physical characteristics, such as typing speeds and rhythms or the frequency, duration, and location of pauses. There are several appropriate terminate and stay resident (TSR) programs available in a DOS environment for recording such data (Janssen, van Waes, & van den Bergh, 1996; Ransdell, 1990). For the Windows environment, we developed FauxWord (Levy, 1994; Levy & Ransdell, 1994), software that emulates a popular commercial word processor while handling all of the keystroke-capturing and -saving chores. The second software component important for certain kinds of process-oriented writing research is one that emulates a multi-channel event recorder—for example, Henderson's (1989) *EventLog*. With such software, judges can watch the video replays, recording the onset and offset of writing activities that cannot be determined solely from the keystroke-capturing programs. Trained judges can reliably assign writing behaviors to theoretically meaningful distinct categories (see Levy & Ransdell, 1994; Ransdell & Levy, 1996b), such as idea translating and revising, which were important processes in the Hayes and Flower (1980) model. Other processes such as planning and reviewing cannot be distinguished by a key-capturing program or a human judge studying a video replay of the unfolding composition, because these processes imply the absence of keyboard activity. The audio channel of the videotape or CD-ROM that contains a concurrent verbal protocol pro-

vides a solution to this problem. For example, if a writer reads aloud parts of a document written earlier that are visible on the screen, a plausible case can be made that a reviewing process is in progress. If, in contrast, the sound track contains information such as "I think that I may want to do . . . next," it is plausible that at that moment the writer is planning what to compose next; subsequent keystrokes can be examined to determine whether such a plan was actually executed.

In an early use of this technology, Levy and Ransdell (1995, 1996) studied changes in writing processes over time. In contrast to previous studies, where writers produced only one or two documents in a single writing session, participants in Levy and Ransdell (1995) returned weekly for 10 composing sessions. A 100-h corpus, contributed by 10 writers, analyzed on a second-by-second basis using the technology described earlier, uncovered interesting regularities in writers' processing that had not been identified previously. These are described next.

The Recursiveness of Writing

The theoretical basis for this research (Levy & Ransdell, 1995, 1996) was derived from Hayes and Flower's (1980) model, a heuristically influential model of writing for more than a decade. Hayes and Flower stressed the recursiveness of writing through cognitive processes such as planning, translating, reviewing, and revising that were repeatedly called during text production. This recursiveness was clearly evident from analyses of verbal protocols obtained while writers composed. We sought a means of depicting the writing processes in such a way that patterns of recursiveness could be compared quantitatively. The search began with the observation that the multiple R^2 was greater than .8 when the first nine writing sessions were used to predict any of several dependent variables during the last writing session. These strong relations led to a variety of ways to represent and compare an individual's writing profile across entire sessions, and eventually, to within sessions as well.

The most interesting of these representations was a matrix that depicted the transitional probabilities that a writer exhibited when shifting between one writing process and another.² Several of these matrices for two typical writers appear in Figure 2. Writers' momentary processes (planning, translating, revising, or reviewing) are represented on the y-axis, and their subsequent process, on the x-axis. The diagonals are empty because they reflect the probability of continuing in the same writing process. For each writer, the patterns of transitional probabilities across weeks (here, Week 5 vs. Week 10) and across 10-min periods within a writing session were compared. Ten-minute time frames were selected to enable us to have at least 100 data points per matrix. The numerical values have been converted to shades of gray to facilitate identification of the important features. Because the greater the numeric value the darker a square becomes, it is clear that the writer represented on the right oscillated between planning and translating. This writer rarely shifted from

Figure 2. Transitional probability matrices for two writers.

either of these processes to reviewing or revising. Most importantly, this pattern appeared for each 10-min time block within a day and across days separated by many weeks. In contrast, the two columns on the left show matrices representing the same time periods for a different writer, whose pattern is clearly different.

These patterns seem to capture an individual's approach to writing. They provide an objective means of characterizing how a writer invokes different processes during the construction of a composition. We named these patterns of transitional probability matrices *writing signatures*, because they reflect writing invariances in much the same way as does an individual's name on a series of checks. Even though there are individual differences between writers, the other 96 daily patterns in this corpus typically resembled those generated by one of the two writers illustrated in Figure 2. To the best of our knowledge, no current theory of writing would have anticipated these within- and between-session invariances or the distinctively different ways in which writers exhibit recursion.

A provocative finding surfaced when final documents associated with these contrasting categories of transitional probabilities were compared. When a writer's transitional probability matrix resembled those on the

right in Figure 2, showing considerable oscillation between only two of the four processes, the final composition was judged to be lower in quality than documents produced by writers who more evenly distributed their processing shifts, as illustrated in the matrices on the left. Separate and apart both from the amount of time devoted to the major writing processes and from individual difference considerations, the quality of compositions depends to an important degree on the pattern that writers use to allocate their engagement in these processes. Patterns that minimize the number of times writers engage in reviewing and revising are strongly associated with poor-quality documents. Document quality is enhanced when proportionally more episodes of reviewing and revising occur (holding constant the total amount of time devoted to these processes), suggesting that many brief revising or reviewing episodes are more effective than fewer, longer ones.

New Theoretical Approaches

Three new cognitively based theories of writing have been presented recently (Grabowski, 1996; Hayes, 1996; Kellogg, 1996). What is remarkable is that they bring writing research into the mainstream of cognitive psychology by their strong emphasis on recent thinking

about working memory. They are all derived from the model proposed by Baddeley (1986), which has mainly been applied in the past to explain working memory in language comprehension and in speech production (Gathercole & Baddeley, 1993).

Of these three new theories of written language production, Kellogg's (1996) is especially interesting, because it contains sufficiently precise detail to make it falsifiable. A basic assumption of his model is that writing, reading, speaking, and listening involve common components. This assumption may foster the development of theoretical links between writing and those much more extensively studied processes. The model also assumes specialized resources for the processing of visual and spatial information, phonological information, and centralized tasks, including reasoning, problem solving, and decision making. Models of working memory proposed by Cowan (1995) and Schneider and Detweiler (1987) make similar assumptions, but Kellogg selected Baddeley's model as his basis because it had been extended to account for research findings in reading, listening, and speaking (Gathercole & Baddeley, 1993).

Figure 3 schematically represents Kellogg's (1996) new model. The upper three panels represent the basic working memory functions that derive from Baddeley (1986). Baddeley proposed a limited-capacity *central executive* that regulates the flow of information within working memory, aids retrieval from long-term memory, and coordinates the processing and storage of information. Support for these ideas about the role of the central executive comes from studies involving secondary tasks such as random digit generation and concurrent digit recall.

The central executive is aided in its work by two slave systems, the phonological loop and the visuospatial sketchpad. The *phonological loop* component is specialized for the storage and rehearsal of verbal material. It has been studied in secondary tasks such as articulatory suppression, word length, phonological similarity, and irrelevant speech (Baddeley, Thomson, & Buchanan, 1975; Colle & Welsh, 1976; LeCompte, 1995; Salame & Baddeley, 1982). In contrast, the *visuospatial sketchpad* is specialized for the storage and rehearsal of visual and spatial, typically nonverbal, material (see, e.g., Logie, 1995).

Following J. Brown, McDonald, T. Brown, and Carr (1988), Kellogg identifies formulation, execution, and monitoring systems of text production. Each of these systems involves two basic-level processes. The formulation system, for example, is associated with planning ideas and translating them into sentences. Information flows through the system in paths indicated by the arrows. Execution occurs under the control of the central executive, in response to input provided by the translating and editing processes. Execution, normally involving motor responses such as the typing of letter strings, provides input to the monitoring system enabling the individual to edit what has just been typed. Although Figure 3 may suggest that text production progresses as the writer formulates the work, executes, and then monitors

Figure 3. Kellogg's model of writing. From "A Model of Working Memory in Writing," by R. T. Kellogg, in *The Science of Writing: Theories, Methods, Individual Differences and Applications* (p. 59), ed. by C. M. Levy and S. E. Ransdell, 1996, Mahwah, NJ: Erlbaum. Copyright 1996 by Lawrence Erlbaum Associates. Adapted with permission.

it, Kellogg is explicit that these systems can function concurrently, when the demands on the central executive do not exceed the capacity limitations of working memory.

Figure 3 indicates that the basic writing processes make differential demands on working memory resources. Planning, for example, is postulated to involve the visuospatial sketchpad and the central executive. When writers begin a text, they may plan by visualizing basic ideas and organizational schemes; recalling them from long-term memory can invoke visual imagery (Paivio, 1986). The activities that constitute planning, including generating ideas, arranging their sequencing and elaborations, recognizing the needs of the audience, and selecting the appropriate tone, are demanding aspects of composition (Flower & Hayes, 1980) that draw heavily on a writer's pool of central capacity. In contrast to the planning process, the translating process is postulated to draw on the phonological loop and the central executive. Further details of Kellogg's model, including much of the empirical data that formed its basis, are described elsewhere (Kellogg, 1996).

As one of the first testable theoretical accounts of writing in more than a decade, the publication of Kellogg's model may signal a shift in writing research toward a greater contact with mainstream cognitive psychology. For such a shift to ever occur, researchers will require writing data that are consistent with the basic tenets of the model. The remainder of this address presents several works in progress that provide some preliminary data that speak to these tenets.

These studies varied the role of the phonological loop, the central executive, and the visuospatial sketchpad to determine how they interacted with each of the writing processes in Kellogg's model. Because all the new models of writing rely so heavily on Baddeley's ideas about the role of the central executive and its slave subsystems, the initial plan focused on the top elements in Figure 3 in order to determine their role in writing. If some critical aspects could be falsified, then all three new the-

ories of writing would require major revising. However, if a consistent pattern of evidence consistent with the predictions from Baddeley (1986) was found, examinations of the merits of Kellogg's extension to the writing domain would be appropriate.

Baddeley (1986) reported years ago that when subjects heard, but were instructed to ignore, irrelevant spoken messages their immediate recall of word lists was impeded. More recently, Madigan, Johnson, and Linton (1994) showed that listening to irrelevant speech reduced the rate at which people produced text. In Kellogg's view, irrelevant speech, which automatically engages the phonological loop, affects formulation, particularly the translating of ideas into text. In this way, irrelevant speech ultimately reduces the person's capability to execute—that is, to provide observable writing. If it could be documented that irrelevant speech influences writing in this way, then perhaps, by other variations, documentation might be obtained to support the premise that the central executive influences writing in a different way. One potential variation might involve giving the writer far more information than the phonological loop can manage, forcing the central executive to deal with the remainder.

Three Preliminary Evaluations of the Role of the Phonological Loop in Writing

In one experiment, Ransdell and Levy (1996a) sought to determine whether unattended irrelevant speech affects the phonological loop in ways sufficient to influence the writers' fluency and quality. Even though writers ignore the messages, concurrent speech may limit the amount of articulatory and phonological processing that people can do while writing expository prose.

The basic design of the experiment was quite simple: undergraduates wrote two argumentative essays, one while listening to irrelevant speech and another under similar conditions but with no background speech. The irrelevant speech consisted of a tape-recorded female voice reading obscure children's fables that the writers were instructed to ignore.

The initial data provide intriguing evidence about the role of working memory in writing. Writers were 14% less fluent (i.e., produced fewer words per minute) when they heard irrelevant speech than when they heard no irrelevant speech ($p < .01$). This effect was consistent with the hypothesis that heavily engaging the phonological loop would affect the translation process. Writers also paused 34.8% more often when they were in the irrelevant-speech condition than when they were not ($p < .01$). It seems that the extra pauses that people took in the irrelevant-speech condition resulted in a decline in words generated per minute. Pauses, after all, signal a disruption in an execution process.

There is considerable research showing that unattended irrelevant speech slows and disrupts reasoning, comprehension, and memory performance (see Gathercole & Baddeley, 1993). One explanation of the irrelevant-speech effect is that such stimuli fully engage phonolog-

ical loop rehearsal processes, resulting in fewer resources being available for the writing task.

To evaluate essay quality, independent judges used an analytic technique to assign points along dimensions such as word choice and assignment, technical quality, content, language and tone, clarity of purpose, organization, and style (Ransdell & Levy, 1996a). The irrelevant speech that writers heard while developing their products did not adversely affect essay quality.

In a second experiment, Marek and Levy (1996) examined the nature of the information presented as irrelevant speech. The theoretical question was whether writers routinely process unattended speech only phonologically. A text-to-speech program that could read aloud ASCII text was used in place of the tape player to present irrelevant speech. This enabled variations of the word order in the children's fables so that coherent text was transformed into anomalous word salads.

Thus, some of the writers would hear

there was once a rich and wicked old king who had a lovely daughter,

and others would hear

once king there a had who daughter old a rich was and wicked lovely.

In both irrelevant-speech conditions, the phonological loop processes exactly the same words on a sentence-by-sentence basis. This leads to four potential outcomes. (1) If information in the phonological loop is continuously processed for meaning, but only for individual words, massive performance degradation during formulation should occur, in comparison with when no irrelevant speech is presented. (2) In contrast, if the coherent text is processed by both the phonological loop and the central executive, then coherent text presented as irrelevant speech should produce larger decrements in writing measures than will anomalous text. (3) A reversal of (2) could occur if the writer differentially processes incoherent, anomalous speech, in an effort to attribute meaning to information when there is none there. (4) Finally, if the writer processes through the phonological loop only the speech sounds of irrelevant speech, neither the meaning of the coherent text nor the individual words will be important when they occur during the writing. This should result in no differences between writing measures gathered in the two speech conditions, but should result in minor degradations in writing measures compared with those for the no-speech control. In fact, fluency scores declined about the same extent as they did in the earlier study (about 11%, $p < .01$) in each of the irrelevant speech conditions, but the difference between these conditions was unreliable. We take this to suggest that writers may process only the phonological information in the speech that they are specifically told to ignore.

Comparing the influence on writing of the phonological loop and of the second slave system postulated by Baddeley (1986), the visuospatial sketchpad, requires a

common paradigm that can be adapted so as to favor the use of one of these systems over the other. The use of one such paradigm is described next.

A Preliminary Evaluation of the Role of the Visuospatial Sketchpad in Writing

The visuospatial sketchpad's primary function in writing is postulated to aid the writer during the formulation processes that include planning and translating. The approaches that we had been using to access the phonological loop were not easily adapted to using the sketchpad. Therefore, we designed a series of simple experiments that put these two slave systems on the same playing field (Lea & Levy, 1996). The primary task was to write for 20 min on one of our standard lab topics. Afterward, we measured writers' performance in a single-task session that engaged either the sketchpad or the phonological loop. The right two thirds of the writer's screen contained a word processing window for essay development.

In the sketchpad engagement, writers monitored the left side of the screen, where they saw an arrow point up, down, left, or right. The position of the arrow changed every 5 sec. To perform the task, the writer must maintain in memory a representation of the x,y -coordinate system and an imaginary placeholder at the 0,0 intersection. Each time a new arrow appeared, the writer was to imagine traversing a standard unit (up, down, left, or right) in the direction indicated by the arrow. Writers clicked the mouse when they noticed that the placeholder had moved away from the x - or y -axis and then returned to the same axis.

In a parallel condition designed to engage the phonological loop without the use of irrelevant speech, writers again monitored the left side of the screen, where they saw either a single alphabetic character or a single digit in simple alternation. These stimuli also changed every 5 sec, but twice each minute the characters were of the same type (successive letters or successive digits). The writers' task was to click the mouse when they noticed the repetition of the same stimulus category. After receiving single-task training on one of these tasks, participants were asked to continue this task while writing an essay on a new topic. In addition to the usual fluency and quality measures, this paradigm enabled us to compare the changes in d' that result when the tasks that continuously engage the visuospatial sketchpad or the phonological loop are performed while a writer is also composing an essay.

Like our research using irrelevant speech, selectively engaging one slave system reliably slowed writing fluency ($p < .001$). As Kellogg's model anticipates, there was a significant interaction ($p = .04$) between the component of working memory that was loaded and the testing condition (either single or dual task), reflecting a greater disruption of fluency by the phonological secondary task than by the visuospatial secondary task. Essay quality declined about 15% ($p < .001$) when either the sketch pad or the phonological loop was engaged. In-

terestingly, d' for the phonological secondary task declined much more ($p = .01$) than the d' for the visuospatial task, as reflected in the interaction between loading task and the testing conditions. Although quality was not affected more by one working memory load than another, both fluency and d' scores deteriorated more in the pairing of the phonological task with writing than in the pairing of the visuospatial task and writing. These results suggest that people have greater difficulty time-sharing writing composition with a phonological task than with a visuospatial task.

A Preliminary Evaluation of the Role of the Central Executive in Writing

Ransdell and Levy (1996a) also focused on the role of the central executive. Here, throughout half of the writing sessions, subjects heard sets of digits to remember and recall. The logic of the experiment was based on Baddeley and Hitch (1974), who argued that a concurrent digit load of sufficient size could fully occupy the phonological loop and strain the capacity of the central executive. Thus, to the extent that the central executive is at least as important as the phonological loop in creating text, both fluency and quality should suffer when people maintain digits in working memory while they compose as compared with while they compose without also managing a memory load task.

In this study, a tape-recorded voice delivered six digits, spaced about 1 sec apart, for writers to store and remember while they composed one of their two essays. About every 30 sec, the voice said the word *recall*. Writers reported aloud as many of the digits as they could remember, then resumed their writing. This sequence was repeated throughout the 10-min period allocated for writing each essay. No concurrent digit load was presented during the writing of a different essay.

Loading the phonological loop with irrelevant speech and targeting the central executive with a concurrent digit load reliably produced decrements in writing fluency. The concurrent digit load reduced writing fluency nearly 40% relative to the no-digit load control ($p < .01$), and pause frequency increased about 77% ($p < .01$). The magnitude of both of these measures was greater than when only the phonological loop was loaded. Moreover, the incidence of pausing at clause boundaries declined 20% ($p < .01$) and the judged quality of the compositions was 16% poorer ($p < .01$) when writers maintained a concurrent digit load in working memory.

Concurrent digit load effects were more pervasive than irrelevant-speech effects: the essays were poorer in quality, the sentences were shorter, pauses were longer and more frequent, and participants were less likely to pause at clause boundaries. Irrelevant speech seems only to affect the number of words produced each minute and how often writers paused while writing continuous discourse. This suggests a greater role for the central executive than for the phonological loop in written language production.

These results are consistent with Kellogg's (1996) model of working memory and writing.³ The model claims that the phonological loop is critically involved in the translation and reading subprocesses. The loop affects to a lesser extent other subprocesses such as planning, executing, and editing, which other research (Levy & Ransdell, 1995; Ransdell & Levy, 1994, 1996b) indicates are key subprocesses for fostering quality. Both irrelevant speech, which engages the phonological loop, and a six-digit concurrent load, which engages the central executive component, disrupt writing fluency. However, only the six-digit concurrent load also disrupts writing quality. These results offer initial support for the hypothesis that working memory contributes to writing fluency through the phonological loop, and that it contributes to writing quality through the involvement of the central executive.

In the irrelevant-speech and concurrent digit load research described so far, models of writing based on Baddeley's theoretical approach were studied. The preliminary studies (Marek & Levy, 1996) described next focus on the role of the writing processes central to Kellogg's model, particularly on how these processes are influenced by the components of working memory. In order to accomplish this, we created a series of writing tasks that facilitate the examination of several of the hypothesized writing processes in isolation from one another.

Preliminary Evaluations of Kellogg's Formulation, Monitoring, and Execution Processes

Refer back to Figure 3 once again. The phonological loop is proposed to influence *formulating*, primarily through the translating subprocess, and *monitoring*, through the reading process. The phonological loop is proposed to have no influence on planning in the formulating process, the editing in the monitoring process, or any aspect of the execution process.

We began to study the functioning of these underlying processes with tasks designed to have a substantial involvement of one process, but little or no involvement of the others. Then, we imposed secondary tasks that, according to the model, have either no influence or a strong influence on the processes required by the primary task.

For example, to study formulating, the computer displayed a series of four to six words, such as *ANGRILY IMPACT REACTED CITIZENS RECENT*. Writers studied these words for up to a minute while they attempted to formulate a single sentence using all of the words. When they signaled that they had accomplished this, the words from the display disappeared, and the writers typed their sentence on the keyboard. Although they produced many sentences in the experiment, the sentences were not necessarily related to one another, as they are in connected discourse.

In a task designed to involve no writing process other than execution, writers copied text that was displayed on one side of their computer screen into a window on the other side. A third task, designed to involve monitoring

independently of formulating, presented several paragraphs that contained grammatical and spelling errors to writers who attempted to both identify and classify each error (e.g., spelling, misuse of comma or apostrophe, verb form or tense).

Writers performed each of these tasks twice, once in silence and once while listening to computer-generated speech, which they were told to ignore. As in our previous studies, the irrelevant speech consisted of the simple fables for children.

When irrelevant speech was presented during the text copying task, designed to examine an execution process that had no direct access to the phonological loop, a small, nonsignificant decrement in words typed per minute occurred, which is what the model predicts. The proofreading task, designed to tap primarily the reading and editing functions in the monitoring process, produced increases in hit rates and false alarm rates when irrelevant speech was introduced, but the changes from baseline were not significant. These results are also in accord with the model. Because both reading and editing were involved, these data suggest either that the role of reading in this task was trivial or that the relationship between reading and the phonological loop in Kellogg's model may need to be respecified.

In the case of the sentence creation task that was designed to reflect the formulation process, irrelevant speech produced highly reliable decrements in the retention measures (7.2%, $p < .001$) but no effect on the time necessary to formulate the sentences. In contrast to the results in our studies summarized earlier, irrelevant speech produced significant decrements (6.9%, $p < .025$) in quality scores in this study.

Writing unrelated sentences, as our writers did here, is a different task from writing an equal number of connected sentences, as in the earlier study. The demands on the writer are different, and the scoring for quality is different. For the formulating study, a quality score was assigned to each sentence along a scale that reflected a combination of meaningfulness and technical quality. Gross mechanical defects such as typographical errors or the failure to end a sentence with a period were ignored. Measuring the quality of a single sentence involves different considerations than does measuring the quality of extended discourse, and we have yet to find a way to measure them on the same scale.

As a consequence, it was not surprising that different outcomes emerged from the two tasks. When writers composed text while hearing irrelevant speech, the writing fluency declined, but the quality of their essays was not materially affected. In contrast, when writers formulated text, one unrelated sentence at a time, the inverse occurred. These differences may well be due to the very different natures of the tasks. The sentence creation task used in the last studies closely resembles the challenge that writers face as they plan an initial, topic sentence for each paragraph of an essay. Schilperoord (1996) and Chanquoy, Foulin, and Fayol (1996), among others, have

shown that pause times are greatest between paragraphs, when writers presumably are reflecting on what they have composed and what they are to produce next. Within paragraphs, pauses are almost always shorter. Such outcomes are often interpreted as indicating the greater resources needed to create the lead sentence of a new paragraph, compared with those needed to elaborate and clarify the main idea. These resources speak to the involvement of a central executive. To the extent that the sentence creation task made heavy demands on the resources provided by central executive, involvement of the phonological loop, initiated by irrelevant speech, may be minor and incidental. This suggests that the effects of irrelevant speech seen in continuous writing may result from the lower demands on the central executive for composing the many sentences in a paragraph that clarify and extend the ideas set forth in the initial sentence. If this is so, we might anticipate systematic differences in fluency and quality for the topic sentence relative to the remaining sentences in a paragraph.

Conclusion

A remarkable presentation given 21 years ago at the society's meeting by Sidowski (1976), a pioneer in the use of computers in psychology, included several of the themes presented here. Sidowski correctly noted that, except for studies in operant conditioning procedures, it was difficult to find research in good psychology journals that used on-line computers. Although this is no longer true, it is certainly difficult to find many reports of writing research today in good psychology journals. As Sidowski admonished us to generate and implement researchable ideas in order to make optimal use of computer developments to open new theoretical and empirical doors, I have tried to identify some new ways in which psychologists can use computer developments to open new theoretical and empirical doors in writing research. The development of new theoretical accounts linking written language production with mainstream cognitive psychology and new methodologies make laboratory studies of writing more feasible and tractable than they were previously.

REFERENCES

- BADDELEY, A. D. (1986). *Working memory*. Oxford: Oxford University Press.
- BADDELEY, A. D., & HITCH, G. J. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.
- BADDELEY, A. D., THOMSON, N., & BUCHANAN, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning & Verbal Behavior*, **24**, 575-589.
- BROWN, J., McDONALD, J. L., BROWN, T. L., & CARR, T. H. (1988). Adapting to processing demands to discourage production: The case of handwriting. *Journal of Experimental Psychology: Human Perception & Performance*, **14**, 45-59.
- CHANQUOY, L., FOULIN, J. N., & FAYOL, M. (1996). Writing in adults: A real-time approach. In G. Rijlaarsdam, H. van den Bergh, & M. Couzijn (Eds.), *Theories, models and methodology in writing research* (pp. 36-43). Amsterdam: Amsterdam University Press.
- COLLE, H. A., & WELSH, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning & Verbal Behavior*, **15**, 17-32.
- COWAN, N. (1995). *Attention and memory: An integrated framework*. New York: Oxford University Press.
- FLOWER, L., & HAYES, J. R. (1980). The dynamics of composing: Making plans and juggling constraints. In L. W. Gregg & E. R. Steinberg (Eds.), *Cognitive processes in writing* (pp. 31-50). Hillsdale, NJ: Erlbaum.
- GATHERCOLE, S., & BADDELEY, A. D. (1993). *Working memory and language*. Hove, U.K.: Erlbaum.
- GRABOWSKI, J. (1996). Writing and speaking: Common grounds and differences towards a regulation theory of written language production. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 73-92). Mahwah, NJ: Erlbaum.
- HABERLANDT, K. (1994). *Cognitive psychology*. Boston: Allyn & Bacon.
- HAYES, J. R. (1996). A new framework for understanding cognition and affect in writing. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 1-28). Mahwah, NJ: Erlbaum.
- HAYES, J. R., & FLOWER, L. S. (1980). Identifying the organization of writing processes. In L. Gregg & E. R. Steinberg, (Eds.), *Cognitive processes in writing* (pp. 3-30). Hillsdale, NJ: Erlbaum.
- HENDERSON, R. W. (1989). *EventLog*. Iowa City: CONDUIT, University of Iowa.
- JANSSEN, D., VAN WAES, L., & VAN DEN BERGH, H. (1996). Effects of thinking aloud on writing processes. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 233-250). Mahwah, NJ: Erlbaum.
- KELLOGG, R. T. (1995). *Cognitive psychology*. Thousand Oaks, CA: Sage.
- KELLOGG, R. T. (1996). A model of working memory in writing. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 57-72). Mahwah, NJ: Erlbaum.
- LEA, J., & LEVY, C. M. (1996, October). *The role of working memory in writing processes and performance: 1. Testing the visuo-spatial sketchpad and the phonological loop*. Paper presented at the European Conference on Writing and Computers, Barcelona.
- LECOMPTÉ, D. C. (1995). An irrelevant speech effect with repeated and continuous background speech. *Psychonomic Bulletin & Review*, **2**, 391-397.
- LEVY, C. M. (1994). FauxWord and FastFauxWord: Windows-based tools for capturing and analyzing the process or written composition. In H. van den Bergh, T. van der Geest, D. Janssen, G. Rijlaarsdam, & S. Sengers (Eds.), *EARLI/ECWC 1994 Writing Conference abstracts*. Utrecht: Utrecht University Press.
- LEVY, C. M., & RANSELL, S. E. (1994). Computer-aided protocol analysis of writing processes. *Behavior Research Methods, Instruments, & Computers*, **26**, 219-223.
- LEVY, C. M., & RANSELL, S. [E.] (1995). Is writing as difficult as it seems? *Memory & Cognition*, **23**, 767-779.
- LEVY, C. M., & RANSELL, S. E. (1996). Writing signatures. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 149-162). Mahwah, NJ: Erlbaum.
- LOGIE, R. H. (1995). *Visuo-spatial working memory*. Hove, U.K.: Erlbaum.
- MADIGAN, R. J., JOHNSON, S. E., & LINTON, P. W. (1994, June). *Working memory capacity and the writing process*. Paper presented at the American Psychological Society, Washington, DC.
- MAREK, P., & LEVY, C. M. (1996, October). *The role of working memory in writing processes and performance: II. Evaluations of formulating, monitoring and executing processes*. Paper presented at the European Conference on Writing and Computers, Barcelona.
- PAIVIO, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.
- RANSELL, S. E. (1990). Using a real-time replay of students' word processing to understand and promote better writing. *Behavior Research Methods, Instruments, & Computers*, **22**, 142-144.
- RANSELL, S. E., & LEVY, C. M. (1994). Writing as process and product: The impact of tool, genre, audience knowledge and writer expertise. *Computers in Human Behavior*, **10**, 1-17.

- RANSDELL, S. E., & LEVY, C. M. (1996a, October). *The effects of irrelevant speech and concurrent digit load on writing quality and fluency*. Paper presented at the European Conference on Writing and Computers, Barcelona.
- RANSDELL, S. E., & LEVY, C. M. (1996b). Working memory constraints on writing quality and fluency. In C. M. Levy & S. E. Ransdell (Eds.), *The science of writing: Theories, methods, individual differences and applications* (pp. 93-106). Mahwah, NJ: Erlbaum.
- SALAME, P., & BADDELEY, A. D. (1982). Disruption of memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning & Verbal Behavior*, *21*, 150-164.
- SCHILPEROORD, J. (1996). The distribution of pause time in written text production. In G. Rijlaarsdam, H. van den Bergh, & M. Couzijn (Eds.), *Theories, models and methodology in writing research* (pp. 21-35). Amsterdam: Amsterdam University Press.
- SCHNEIDER, K. A., & DETWEILLER, M. (1987). A connectionist/control architecture for working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 21, pp. 54-119). New York: Academic Press.
- SIDOWSKI, J. (1976). On-line instrumentation in psychology: Dildo or the real thing? *Behavior Research Methods & Instrumentation*, *8*, 52-56.

NOTES

1. There have been additional thousands of treatments of writing by scholars in other disciplines, but almost universally, these are studies of written products. These have provided few useful insights for cognitive psychologists about the processes or mechanisms that writers use to generate their finished text.

2. With the techniques described earlier, it was possible to reliably categorize writing epochs as brief as 1 sec as exhibiting one of the four major processes (plus an "other" category). In constructing these matrices, however, the focus was not on how much time the writer devoted to any particular process, but how, when, and how frequently the writer's behavior indicated a shift to a different writing process.

3. This is not to say, however, that the results are inconsistent with other theories, especially those based on differential attention. The point of these initial studies was not to contrast theories but, instead, to determine whether the extensive work on the role of working memory could be extended successfully to include written language production.

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