THE PROCESSING DEMANDS OF WRITING

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Final Draft of chapter in MacArthur, C., Graham, S., & Fitzgerlad, J. (Eds.). (forthcoming, due Jan 2005). *Handbook of Writing Research*. New York: Guilford Publications.

INTRODUCTION

To facilitate the production of the text that you are now reading I (MT) am using a common word processing application running on a personal computer. As I write, the word processor is monitoring what I type for spelling errors. If I asked it to, it would also check to see if the text I produce is grammatical (according to its own, somewhat arcane criteria). Elsewhere on the computer I have an email application running, which is monitoring for incoming mail, and bibliographic software that communicates with the word processor when I require it to do so. These are just the things I know about. In the background there appear to be a further twenty-eight processes running, at least some of which are, I assume, essential to the effective working of my computer. Each of these is constantly either manipulating information or standing in preparedness to do so. To accomplish all of this, each process draws, to varying degrees, on both the computer's random-access memory and its central processor. My current computer has plenty of RAM and a fast processor, and will multi-task quite happily across all of these processes. This would very definitely not have been true of the computer that I used ten years ago. On that machine running just two applications at once resulted in a radical reduction in performance and any further demands would make it grind to a halt.

There is, of course, another information-processing device involved in the production of this text. Whilst I am writing my mind is either simultaneously engaged in or rapidly switching between processes which perform all or most of the following functions: monitoring the thematic coherence of the text; searching for and retrieving relevant content; identifying lexical items associated with this content; formulating syntactic structure; inflecting words to give them the necessary morphology; monitoring for appropriate register; ensuring that intended new text is tied into the immediately preceding text in a way that maintains cohesion; formulating and executing motor plans for the key-strokes that will form the text on the screen; establishing the extent to which the just-generated clause or sentence moves the text as a whole nearer to my intended goal; and revising my goals in the light of new ideas cued by the just-produced text. These processes cannot all be performed simultaneously. Attempting to do so, as with my ten-year-old computer, would result in overload and writing would stop. The fact that I am writing this at all, therefore, is testament to the writing system's ability to coordinate and schedule a number of different processes within the limited processing resources afforded it by my mind.

Even with this coordination, the production of anything other than trivial text often comes close to crashing the system, as the quote below graphically describes.

> *The initial gurgitation of material builds up a high pressure of nervous excitement leading to such physical symptoms as redness in the face, headache, inability to sit down, lapses of concentration and extreme short temper, especially on interruption. Ordering the material presents agonising problems of rethinking [....] problems of sequencing often lead to inability of write down a coherent sentence. The final process is well nigh unendurable. (Anonymous writer quoted in Lowenthal & Wason, 1977, p 781)*

Or, as Flower and Hayes (1980, p. 33) put it:

> *The writer must exercise a number of skills and meet a number of demands – more or less all at once. As a dynamic process, writing is the act of dealing with an excessive number of*

simultaneous demands or constraints. Viewed this way, a writer in the act is a thinker on full-time cognitive overload.

This chapter explores current understanding of the ways in which the complex set of processes associated with the production of multi-sentential text are managed within the limitations imposed by structural features of the writer's mind. These processing limitations are inescapable and are therefore implicated in all theories that seek to explain text production in humans. This has been recognised by a number of researchers with the result that there has been a recent modest growth in writing research explicitly exploring working memory effects (see, for example, overviews by Chanquoy and Alamargot, 2002 and McCutchen, 1994; 1996). This chapter selectively reviews some of this research. Our aim is to paint a general picture of what is currently known about how processing limitations affect the functioning of the writing system and to tentatively suggest a framework for future research. In the first section, we explore the various ways in which text production might be resource demanding. The set of phenomena that are sometimes attributed to a catchall "limited capacity working memory" have, we argue, several possible causes. These include, at least, effects associated with processing bottlenecks, with crosstalk amongst outputs, and with the transient nature of short-term memory. Our assumption is that theories that capture the complexity of the writing system need to be based in a sophisticated understanding of how that system might be constrained. In the light of this discussion, the second half of the chapter reviews examines ways in which the cognitive demands of writing can be either adapted to or overcome.

PROCESSING CONSTRAINTS

Cognitive psychologists vary in how they set about accounting for limitations in the mind's capacity to process information. Two relatively distinct literatures have developed, each addressing different, but complementary research questions. First, research exploring dual task interference (e.g., Pashler, 1994a) starts from the observation that attempting to perform two tasks in close temporal proximity, even when these tasks are very simple, typically has a detrimental effect on performance on one or both tasks. Research in this area seeks to explain the (probably multiple) ways in which this interference might occur. Second, research exploring effects associated with the transient nature of short term memory (STM) starts from the observation that there are severe limits to our ability to retain information in conscious awareness. The focus of this research is the set of mechanisms by which the mind is able to keep information available for immediate processing. An illustration of work in this area is the recent debate about the role of Baddeley's "phonological loop" in memory for word lists (see, for example, Larsen & Baddeley, 2003 and subsequent commentary). Theory in both of these areas has been based on observation of people performing very simple tasks (pressing a key in response to a tone, recalling short lists of words) in controlled experimental conditions. The challenge for writing researchers is to explore how these basic processes constrain and are managed across the complex layers of information-processing that comprise our ability to produce coherent text.

Dual task interference

When our minds attempt to perform two cognitive tasks at the same time this can sometimes result in degraded performance of one or both tasks: trying simultaneously to read and hold a conversation is likely to result in either poor comprehension or poor communication, or both. In the context of written production, understanding the mechanisms underlying this phenomenon is important because there is potential during normal writing for the writing system to attempt to perform two tasks at once. It is also important because writing researchers have used experimental methods that deliberately seek to elicit dual-task effects.

Dual-task experimental methods involve participants performing a resource-demanding secondary task alongside producing text. Secondary tasks have taken a variety of forms including monitoring characters or shapes displayed alongside text as it appears on the computer screen (Lea & Levy, 1999), responding to auditory reaction time probes ("press the button when you hear 'stop'; e.g., Kellogg, 2001a), listening to unrelated speech or music (Levy & Marek, 1999; Ransdell & Gilroy, 2001), rapidly repeating a single syllable (Chenoweth & Hayes, 2003), or retaining in memory digits (Ransdell, Arecco, & Levy, 2001), words (Bourdin & Fayol, 2002), or shapes (Kellogg, 1999). Degraded writing performance is taken as indication that there is overlap between the cognitive resources required for performance of the secondary task and those required for writing. If, as Chenoweth and Hayes (2003) found, asking participants to repeat a single syllable while writing increases the number of grammatical and spelling errors that they make, then we might conclude that syllable-repetition shares resources with the components of the writing system that are responsible for generating sentence and word structure. If the resource demands associated with syllable repetition are known, this then provides insight into the cognitive mechanisms associated with the primary (writing) task. Building up a picture of the resource demands of individual sub-processes should therefore allow conclusions to be drawn about which of these sub-processes compete for resources during text production.

Degraded performance on the secondary task can be interpreted in a similar way. A series of studies by Kellogg and collaborators found that the time taken to respond to auditory probes that interrupt writing mid-flow is greater at some points of the writing process than at others (Kellogg, 1988; Kellogg, 1990; Kellogg, 2001a; Olive & Kellogg, 2002). They interpret variations in reaction time in these studies as variation in the cognitive effort that the writer is devoting to the writing task at the time at which the probe occurred.

Capacity explanations

A prerequisite for interpreting findings from research of this kind is an understanding of the ways in which performance of one task might interfere with the performance of another. One possibility is that cognitive capacity is a fluid resource that is shared amongst some or all mental processes. Well-practiced components of the writing system – the motor planning necessary for keyboarding by a competent typist, for example – will run successfully while making very limited demands on cognitive capacity. Other components – those required to solve the "problems of sequencing" identified by the writer quoted in our introduction, for example – may make much higher demands. Performance on all tasks can proceed without detriment to any of them, as long as total demand does not exceed available capacity. When it does, one or more tasks will be performed less well. For the frustrated writer quoted above, organising the text appeared to overload capacity with detrimental affects for the formulation of syntactically correct sentences.

At its simplest, cognitive capacity can be thought of as a single resource that is shared across all currently-running, resource-demanding processes (e.g., Kahneman, 1973). This has been the default assumption amongst writing researchers (e.g., Fayol, 1999; Kellogg, 1987; McCutchen, 1996; Olive & Kellogg, 2002; Swanson & Berninger, 1996b). Alternatively, capacity may be thought of as fractionated, with different resource pools being available to different tasks, depending on the particular representational code that a task manipulates (e.g., Caplan & Waters, 1999; Navon & Gopher, 1979). In an influential account, Baddeley (1986) has argued for distinct phonological and visuo-spatial resources. There is some evidence that this distinction holds true during text production. Kellogg and Catterton, 1996 (cited in Kellogg, 1999) asked participants to retain digits in memory (a phonological task) or shapes in memory (a visuo-spatial task) whilst composing sentences. Both spatial and digit preloads resulted in reduced sentence length and in increased production time compared to a no-preload control. Effects were greater, however, for digit preloads. Similarly Lea and Levy (1999), using a concurrent monitoring task, found greater detrimental effects on fluency (words transcribed per minute) with phonological monitoring compared with a visuo-spatial monitoring.

If different resource-pools exist, then it is also likely that different pools are drawn upon by different components of the writing system.

Kellogg (1999; 1996) observed that planning – the processes by which writers decide content and structure for their text – is likely to involve proportionally less phonological and more visuo-spatial processing than realising this content as full sentences: Realising text as sentences must necessarily involve some degree of phonological encoding, whereas planning may be performed in part by manipulating pre-verbal codes. It is likely that these pre-verbal codes are, in part, spatial. The notes that writers' sometimes produce in advance of drafting full text often include boxes, arrows, tables and other spatial features, and writers' talk about their text often includes spatial metaphors ("I think I'll put that section there"). Galbraith et al (in press) present evidence suggesting that a secondary task designed to tap spatial but not visual resources during initial planning has no effect on participants' retrieval of relevant content. However, they found that this task reduced the extent to which ideas were reorganised during planning and that this was associated with a reduction in the quality and structural complexity of the text that was subsequently produced.

Alternatives to capacity explanations

Explanations for dual task performance in terms of graded sharing of communal resources are seductively simple and all-embracing. If two tasks interfere, then they share resources, if not then either they don't share resources (assuming multiple resource-pools) or one or more of the tasks are automatic, and therefore not resource-demanding. The capacity metaphor thus provides an easy explanation for, for example, developmental effects. Children necessarily devote a high proportion of available capacity to the orthographic processing necessary for the production of correctly spelled words and to the grapho-motor processing associated with shaping letters on the page. Devoting resources to these low-level processes leaves less capacity for syntactic processing, content-retrieval, rhetorical-structuring and so forth (e.g., Fayol, 1999). Hence, novice writers produce shorter and less complex sentences and texts compared with those of writers who have achieved greater levels of orthographic and grapho-motor automaticity. Task effects can be explained in a similar way. Composing narratives by hand interferes with performance on a secondary probe response task to a substantially lesser extent than composing persuasive text using a word-processor (Kellogg, 2001a). Kellogg explains this effect by arguing that writing by hand (a well practiced motor skills) and composing narratives (a familiar genre) engage less cognitive capacity than keyboarding (a less well practiced motor skill) and persuasive writing (a less well practiced genre).

There are, however, problems here relating to both falsifiability and explanatory power: It is sometimes difficult to imagine patterns of data in research of this kind that could not be explained by some combination of capacity and automaticity effects. Some gains in explanatory power may be achieved by hypothesising multiple resource types in that this invites theorising about the kinds of representations that are manipulated by different writing sub-processes. Arguably, however, this is at the cost of further reducing falsifiability (Christiansen & MacDonald, 1999). It is also not always clear what capacity explanations for dual-task effects tell us about underlying cognitive processes. Translating text into full sentences involves a complex set of interrelated mechanisms. Finding, for example, slowed probe reaction times when the writers' goal is to persuade suggests the need for detailed enquiry into the cognitive processes that are particular to persuasive writing. Arguably capacity accounts in this and similar contexts, by accounting for behaviour in terms of ubiquitous structures that operate independently of the writing process, tend to prematurely curtail this detailed investigation. In a more general context, Navon (1985) makes this point forcefully, arguing that advancing capacity allocation as an explanation for patterns of performance is like selling stones which make perfect soup, but only so long as they are combined with vegetables, meat, herbs, salt, pepper…and so forth.

However, there are other possible explanations for dual-task interference that do not invoke competition for limited capacity. One alternative possibility, for example, is that the content of the output that results from performing one task interferes with the processing of another (Navon & Miller, 1987). The fact that monitoring letters presented to writers' peripheral vision slows written production (Lea & Levy, 1999) could be seen as evidence that phonological processing capacity is shared between letter-monitoring and writing. Alternatively, it may be that outputs from the monitoring task – frequently changing phonemes – act as unwanted input to, and thus interfere with, writing sub-processes that take phonetic code as input, such as reading just-written text. Another possibility is that interference occurs as a result of competition not for shared capacity but for one or more shared (or "bottleneck") mechanisms (Pashler, 1994a). The analogy here is of two road workers who share a single spade. This arrangement will result in a loss in productivity if, and only if, both of them want to dig a hole at the same time. If this situation occurs, then one worker will proceed with digging their hole at a normal pace whilst the other waits, inactive, until the first hole is complete. Productivity losses as a result of letter monitoring may, therefore, occur because on occasion a low-level sub-component of the writing process is temporarily halted because one or more of the mechanisms that it needs is being used to perform the letter-monitoring task.

It is probably the case that capacity, bottleneck and cross-talk models provide equally good fits to much of the data that we discuss in this chapter (cf Navon & Miller, 2002). However, one substantial advantage of crosstalk and bottleneck explanations of dual task interference is that they provide a framework for future enquiry. Bottleneck explanations, for example, necessarily hypothesise a specific mechanism that is required for the completion of both the writing and the secondary tasks. The theory ultimately stands or falls on whether or not this mechanism can be identified, and the enquiry involved in doing so will deepen understanding of how the writing system is configured.

Transient memory

Young children, as they are developing the ability to construct more complex utterances, often run into the following problem. They start with the intention of expressing an important idea. Excitedly, they start speaking. At some point they experience difficulty in retrieving the word needed to express a particular concept, or they identify the word but have difficultly retrieving its correct pronunciation. This results in delay during which they might make several false starts until finally, perhaps with prompting, they produce the desired word. There is then another pause, the child's face clouds, and they exclaim in annoyance, "Oh, now I've forgotten what I was trying to say".

Sentence production is typically theorised as a sequence of discrete processing stages from word retrieval, through developing syntactic structure and retrieving phonology or orthography, to motor planning and execution. These processes, or their various constituent components, are capable of running in parallel. Thus, both in speech (Smith & Wheeldon, 1999) and in writing (Chanquoy, Foulin, & Fayol, 1990) people output the first words of a sentence while, behind the scenes, words for later parts of the sentence are still being retrieved. It is this cascading of processes that offers the potential for adult language production to be relatively free of pauses.

Problems resulting from the limited capacity and transience of STM are likely to multiply when a writing task requires the production of multiple sentences. Sentences in coherent extended text do not simply communicate isolated packets of information. For the text to be successful authors need to ensure that new sentences let readers associate the new content that this sentence expresses with their understanding of the text that they have already read. Achieving this coherence requires both that the new sentence makes local ties with the preceding one, and that it advances the global message of the text. To make this possible the author requires not only access to the content-to-be-expressed, but also to (some of) the content and surface structure of the preceding sentence, and to a higher-level representation of the intended rhetorical structure for the completed text. To maintain fluency, this information needs to be accessed rapidly and relatively effortlessly, a requirement that is likely to tax substantially the minds short term storage capabilities.

Evaluating transient memory effects

There are perhaps three different ways in which transient storage considerations might be implicated in accounts of writing competence (see for example, Swanson, 1996). First, it may be that at some fundamental level people vary in STM capacity, independent of the particular task that is being performed. Good short term memory ability will therefore lead to improved performance not just when writing but on all information processing tasks that require temporary storage.

Second, it is possible that as writers become more experienced they develop domain-specific memory-management strategies that allow them to make better use of the capacity that is available to them. If this is the case then experienced writers may develop an ability to retain information whilst writing but not show related improvements in, for example, ability to retain digits in a simple memory task.

Third, writers may vary in the extent to which components of the writing system draw on or interfere with storage mechanisms. For example it is probable that about-to-be-executed words are temporarily stored as a phonological code (which writers experience as hearing an inner voice – Chenoweth & Hayes, 2003; Witte, 1987). Getting this phonological representation onto the page requires retrieval of the spellings for its constituent words. Literate writers probably spell the vast majority of words without recourse to phonological (inner-voice / inner-ear) mechanisms. However, if the to-be-executed words include one or more with unfamiliar spellings, or if the writer suffers from a spelling-specific cognitive deficit, then attempting to retrieve a spelling may overwrite existing phonologically-stored information, and the remainder of the to-be-written sentence will be lost or damaged. And because the message-level representation for the sentence will now have decayed, the writer will have to engage in some sort of strategic activity to recreate the lost content. It is likely, therefore, that the transience of STM will be less problematic if basic writing-specific abilities are well developed.

Writers may, therefore, vary in general STM capacity, in writing-specific memory management skills, and in the efficiency with which they execute components of the writing system. Each of these factors may affect writing performance, and it is worth exploring their relative importance. One way of determining general effects of STM independently of writing-specific effects is to examine developmental changes in the strength of the relationship between STM capacity and the quality of the written product. If practice results in better memory management or greater automaticity in some writing sub-processes then as writers mature STM capacity should become less predictive of writing performance. In fourth and sixth grade students, Swanson and Berninger (1996a) found strong relationships between scores on a composite STM measure and both spelling and handwriting performance, and, within this narrow range, the relationship was largely independent of age. Across high school years, however, and with writing success measured just in terms of grammatical errors, there is some evidence of a marked decrease in the predictive power of STM. Daiute (1984) found that in eighth grade, forty percent of the variance in number of errors was associated with variance in verbatim sentence memory. This reduced to just one percent for students in twelfth grade.

Another way of teasing out “pure” STM effects is to contrast simple measures of short-term capacity with measures that involve participants retaining information whilst simultaneously engaging in a processing task (Daneman & Carpenter, 1980). A simple measure of (phonological) STM capacity might involve participants recalling increasingly long lists of pronounceable nonsense syllables immediately after presentation. with a participant’s span recorded as the longest list that they can correctly recall. By contrast, a memory-plus-processing (or *complex span*) task (e.g., McCutchen, Covill, Hoyne, & Mildes, 1994; Ransdell & Levy, 1999; Swanson & Berninger, 1996a) might involve presenting participants with word lists of varying length. After presentation they are required to write, for each word, a single sentence containing that word. A participant's "writing span" is the maximum number of sentences that can be produced in this way. (Ransdell and Levy found that this rarely exceeded four.) Complex span therefore represents a measure of STM performance within a specific processing context.

Complex span tasks have been used extensively in reading research and in that context appear to be better than simple span at predicting comprehension (Daneman & Merikle, 1996). Complex span performance in the context of writing has received much less attention. In college students, Ransdell and Levy (1999) found correlations between writing span and text quality ranging from .20 to .30, depending on the exact nature of the span task, and from .39 to .47 for correlations with rate of production. They did not, however, include a simple span measure in their analysis. Hoskyn and Swanson (2003), in a broad sample comprising adolescents, adults in their thirties, and elderly adults, found that a composite of several verbal complex-span measures was much better than a simple digit span measure at predicting the structural complexity of participants' texts. In much younger children (grades 4 to 6) Berninger et al (1994; Swanson & Berninger, 1996a) found correlations of .24 between writing quality and both an STM measure involving syllable recall and a complex-span task involving listening to and then writing down sentences. They found that a composite of verbal and verbal-executive complex-span measures contributed more to writing fluency (measured both in number of words and in number of clauses in completed texts) and text quality than did a composite of STM measures. However, STM capacity proved to be a better predictor of handwriting quality and spelling accuracy.

Interpreting findings in this area is complex, not least because there are multiple ways of operationalizing both writing span and writing performance. There does, however, seem to be good evidence to suggest that factors associated with the extent to which STM is used during writing are important in determining writing performance, independent of underlying STM capacity. Moreover, the fact that writing-span tasks appear to contribute unique variance to performance, and that this effect remains even when other factors associated with verbal skill are controlled for, suggests that these effects are not simply due to varying efficiency of the writing-system's component processes (Berninger et al., 1994). Research is needed that studies the full range of ages over which composition skills are likely to develop. However, existing findings suggest that part of developing writing expertise involves developing writing-specific memory-management strategies.

Processing constraints and the writer

In summary, then, we have painted a picture of the writing system as a delicately balanced set of interrelated processes. These processes must be carefully scheduled if they are to receive and pass on information in a way that is fluent and uninterrupted. Failure in this scheduling can result in two processes competing for a single mechanism and / or in interference between process outputs. Because outputs from upstream processes are transient – their traces decay rapidly – any hiatus is likely to have substantial repercussions for the writing process as a whole. Activity to repair these negative effects, to reinstate the intended message or reconstruct a particular turn of phrase for example, is likely to form a major part of the production of anything other than the simplest of texts.

For most writers, and most writing tasks, smooth flow is repeatedly interrupted. For example, production of the fourth and fifth sentences of the previous paragraph (which were composed using a key-stroke logging program) involved a total of sixty pauses of two or more seconds. This was despite the writer (MT) experiencing "knowing what he wanted to say" before starting to write. To produce the final 429 characters these sentences (in their first-draft version), over twice that amount of text was written and then deleted. There has been a tendency, based in Hayes and Flower's original conception of the writing process as being under strong executive control, to assume that this stop-start behavior results from writers moving deliberately and strategically through repeated plan-translate-revise cycles. Our impression, however, is that much of the minute-by-minute activity associated with getting ideas down on paper is not controlled in this way. Repeated hesitation, backtracking and rewriting are, at least in part, a direct result of the need to repair problems that necessarily occur when complex information processing occurs within the constraints of limited cognitive resources. Writers do not calmly select different writing sub-processes as if they were tools to be used as and when needed. They are, in McCutchen's analogy, like a switchboard operator continually, and at times frantically, trying to coordinate and direct the inputs to and outputs from several component processes (McCutchen et al., 1994). How this coordination might be achieved is the focus of the remainder of this chapter.

OVERCOMING PROCESSING CONSTRAINTS

Developing writing maturity involves tailoring the writing system so as to minimise concurrent demands on the writer's cognitive resources. The discussion in the previous sections points towards three broad ways in which this might be achieved: (1) Subcomponent skills, and particularly low-level skills associated with transcription (handwriting / keyboarding) and spelling, can be practiced to the extent that they rarely invoke higher-level processing mechanisms. (2) Writers may develop specific skills for maximising the efficiency with which they use transient memory resources. (3) There are several strategic steps that writers can take – preplanning, making notes, rough-drafting and so forth – that serve to reduce the number of processes that the mind has to juggle during composition. We briefly discuss each of these in a little more detail in the sections that follow.

Developing automaticity in low-level components

For present purposes, we will think of a process as automatic if it occurs without voluntary control and interferes minimally with other processes. Pashler (1994b) observes that practice can lead to automaticity by streamlining the way in which a task is performed and thus decreasing the period for which potential bottleneck mechanisms are engaged. If, for example, spelling can be achieved without the writer actively invoking mechanisms for explicit retrieval from long term memory (LTM) – if the writer can avoid having to stop and say "now are there one or two c's in necessary?", or avoid consciously computing subject-verb agreement errors (Fayol, Hupet, & Largy, 1999) – this will leave these retrieval mechanisms free for exploring possible content.

Spelling and handwriting, the two low-level processes that are most obviously required in written production but not in speech, are obvious candidates for automatization. Bourdin and Fayol, in a series of studies with varying age groups, explored differences in recall under spoken and written conditions (Bourdin, 1999; Bourdin & Fayol, 1994, 1996, 2002). These studies tend to confirm that when written production is less practiced it interferes with conscious retrieval processes. In simple word-recall tasks, both second and fourth grade children recalled substantially fewer items when their responses were written than when their responses were spoken (Bourdin & Fayol, 1994). For adults, however, this effect was absent or even reversed, with slightly better recall with written responses. Predictably, adding composition demands, with participants producing sentences containing the words to be recalled (a "sentence-span" task) rather than recalling them in isolation, also gave poorer written recall and better spoken recall in children. Again, this effect was not found in adults (Bourdin & Fayol, 1996). However, when the further demand that sentences need to be linked (a "text-span" task) was added, and when the words presented were unrelated and so difficult to combine into a coherent text, adults then also performed less well in the written modality. This suggests that even when spelling and handwriting are very well practiced, they can still compete with higher-level processes.

Of course Bourdin and Fayol's findings conflate spelling and handwriting effects. However, other research suggests that there is potential for interference between higher level processes and both spelling and handwriting (Fayol, 1999). Fayol and co-workers have found that spelling errors (specifically subject-verb agreement errors in French) increase in both children (Totereau, Thevenin, & Fayol, 1997) and adults (Fayol, Largy, & Lemaire, 1994) when combined with memory tasks. With more natural writing tasks, difficulties with spelling words appear to narrow the range of vocabulary that writers use. Wengelin (in press) found that her sample of adult dyslexic writers were more likely to pause mid-word, and showed substantially lower lexical diversity than non-dyslexic controls. These two phenomena appeared to be related with a high proportion of the variance in lexical diversity predicted by the extent to which writers paused mid-word and the extent to which they engaged in concurrent editing. This suggests, perhaps, that spelling retrieval interferes with processes involved in lexical retrieval, and/or that mid-word pausing in itself results in the loss of lexical items that are awaiting transcription but are less common and therefore have a lower level of activation.

There appears also to be potential for interference between the graphical processing associated with transcription and higher-level writing processes, although the evidence here is rather less direct. Bourdin and Fayol (2000) found that in second grade children repetition of even a very simple graphic pattern whilst orally recalling word lists resulted in a thirty percent reduction in recall. If, as this suggests, very low-level grapho-motor processes are capable of interfering with retrieval from LTM then training specifically focussed on improving children's handwriting should benefit not just handwriting neatness but also other aspects of text generation. This appears to be the case, at least in terms of the fluency with which text is produced (Berninger et al., 1997).

The findings summarised briefly here therefore suggest both that there is potential for conflict between low-level output processes (spelling and handwriting) and processes associated with generating and structuring content, and that with increased expertise in these low-level skills this conflict becomes less likely.

Efficient memory-management

Part of becoming an efficient writer may involve writers developing specific ways of either maintaining focus on currently important information or of using limited transient memory capacity to maximum effect. Although both of these possibilities have been mentioned in the writing-research literature, neither has seen much direct research attention.

Several researchers have suggested that performance on complex span tasks may best be predicted by the extent to which participants are able to focus attention on currently-important information and to suppress information that might interfere (e.g., Kane & Engle, 2003). Writers who are able to suppress, for example, tangential ideas that are activated through association with words currently being written, or who are able to temporarily ignore a poorly turned phrase, are more likely to get to the end of the sentence before their intended message decays. Ransdell and Levy argue that certain writers, identified by their high reading-comprehension skill (1999) or multilingualism (2001), may be particularly good at suppressing irrelevant information. Further, they suggest that skilled readers exhibit what they describe as “resource flexibility” – the ability to deliberately shift attention between potentially competing task demands. In their research, participants performed a written-sentence span task under instructions either to maximise memory performance or maximise sentence quality. Skilled readers showed better recall when memory was emphasised and produced longer sentences when sentence quality was emphasised, suggesting an ability to shift processing priorities strategically. This effect was not present in participants with lower reading skill.

Another approach to memory management is to reduce the amount of information that needs to be held in STM. As discussed above, writers require access not just to a message-level representation of the sentence that is being produced but also, amongst other things, to more global representations (macropropositions) that allow the writer to relate the content currently being transcribed to its wider context within the text. The more rapidly this information can be accessed during production, the less disruption its retrieval will cause. One mechanism by which rapid retrieval might be achieved involves structuring important information in LTM in such a way that it can be retrieved more or less effortlessly in response to specific cues in STM, an arrangement that Ericsson and Kintsch (1995) describe as Long Term Working Memory (LTWM). Several authors have suggested that LTWM plays an important role in text production (e.g., Chanquoy & Alamargot, 2002; McCutchen, 2000), and it has been invoked as an explanation for reduced secondary task interference in multilingual writers (Ransdell et al., 2001) and in writers with high domain knowledge (Kellogg, 2001b).

Long Term Working Memory has intuitive appeal as a memory management strategy in writing. It clearly is not possible for writers to hold active in STM all of the information that they require to contextualize the sentence that they are currently producing. So, while a sentence is being composed, access – and preferably very rapid access - is required to global representations. For LTWM to fulfil this function, writers would need to develop specific schematic structures that allow chunking, labelling, storage, and subsequent retrieval of the information that they wish to communicate. Schemas representing typical text structures may serve this kind of memory-structuring function (e.g., Carey & Flower, 1989; Klein, 1999). As yet, however, little is known about how LTWM functions during writing.

Effects of writing strategy on processing demands

How writers choose to divide a writing task into subtasks, and how these subtasks are sequenced – their "writing strategy" – may have important consequences for accommodating writing within processing constraints. If, for example, content determination can be performed independently of sentence construction, or if sentence construction can be separated from transcription, then this removes the possibility that these processes might conflict.

Both outlining (producing structured notes) and rough drafting (producing full text, but with relaxed rhetorical constraints) are strategies that allow content planning to be conducted free of the demands of constructing well formed and coherent text. There is consistent evidence that outlining does benefit writing (e.g. Kellogg, 1988; 1990), and some suggestion that certain forms of rough drafting may also be beneficial (Galbraith & Torrance, 2004). It is, however, unclear precisely how these strategies reduce processing constraints. In a series of experiments Kellogg considered a number of possible explanations for the beneficial effects of outlining. The first was that storing the writer's plan externally frees space in working memory for other processes, enabling them to be carried out more effectively. However, Kellogg found that outlining was equally effective regardless of whether it was performed mentally or in external note-form. Thus, although external storage may be important in other contexts (see, for example Benton, Kiewra, Whitfill, & Dennison, 1993), it cannot account for the beneficial effects in Kellogg's experiments. A second possibility is that separating planning content from translation (realizing planned content as full text) enables more cognitive effort to be devoted to each process individually. Kellogg tested this by comparing performance on a secondary probe reaction time task administered while writers were producing the text itself, predicting that more cognitive effort (reflected in longer response times to the secondary task) would be devoted to translation in the outline conditions. He found no difference between conditions, suggesting that the same amount of effort was devoted to translation in both cases. Taken together, these results suggest that the beneficial effect of outlining are not a consequence of more resources being available for individual processes. Kellogg concludes instead that the crucial effect of outlining is that it separates the planning and translation components of writing, enabling writers to organise their ideas more effectively prior to writing, and to focus their attention more exclusively on translating ideas into words during the production of the text itself. The effect therefore does not appear to be a consequence of reducing competition for a limited pool of resources, but rather of reducing interference between the processes, caused perhaps either by task switching or by conflict between outputs of the different processes.

Rough drafting has been studied less frequently and most research has reported no beneficial effects compared to polished drafts (e.g., Kellogg, 1988). There is a history, however, of writers espousing the benefits of producing a series of rough drafts as a strategy for generating content by (e.g., Green & Wason, 1982). These accounts suggest that if rough drafting is effective this is not so much because it separates planning content from translation, but again because it reduces interference between processes associated with exploring the intrinsic organisation of writer's topic knowledge and processes associated with satisfying rhetorical goals (Galbraith, 1999).

A less frequently used strategy, but one which is becoming increasingly practicable with developments in word-processing software, is replacing manual transcription by speech input. As we discussed above, while transcription (grapho-motor and spelling) expertise is poorly developed there is potential for these processes to interfere with content determination. If, then, children were to write by dictation, we might expect gains not just in spelling accuracy but also in compositional quality. This appears to be the case: Children, and particularly children with learning disabilities, tend to create compositionally better texts when dictating than when writing by hand (DelaPaz & Graham, 1997; Quinlan, in press).

It is less clear, however, that experienced writers, who have gained automaticity in transcription, will benefit in the same way (Williams, Hartley, & Pittard, in press). In a small study of our own (Torrance & Baker, 1998) we compared probe response times for mature writers composing by hand, by keyboarding, and, by speaking (using a human typist to permit perfect speech recognition). Contrary to expectations, we found that the speech input condition interfered more with the probe response task than both handwriting and keyboard-input word processing. One possible explanation for this finding is that the speech input gave an unfamiliar, and unusually rapid, tempo to the composition process. If writing involves a delicately balanced cascade of processes, some of which run in parallel, then changes in the pacing of transcription may disrupt this balance, at least until the writer has adapted to the new rhythm. Chanquoy, Foulin and Fayol (1990) found that experienced writers, but not eight year olds, modify the rhythm of their writing process, increasing inter clause pause lengths and decreasing intra-clause transcription rate to accommodate conceptually more complex material. This suggests that pacing might be particularly important in the management of retrieval from LTM. There is some evidence to support this claim. As we noted earlier, although children recall better when speaking than when writing and the reverse appears to be true for adults (Bourdin & Fayol, 1994). Grabowski (in press) has replicated this effect and, through a series of carefully controlled experiments, concludes that the benefits of recalling-by-writing are rooted in the fact that writing forces a slower pace on the recall process.

The effect of writing strategy on writing process is, therefore, complex, and the efficacy of a particular strategy is likely to depend on more that just the extent to which it liberates processing capacity during translation. One final illustration of this comes from research exploring the ways in which reading back over just-written text affects the writing process. While producing full text writers frequently pause and read back over the one or two sentences that they have just written. This local reviewing does not, however, typically result in changes to the text. Rather, the sequencing of read-back in relation to planning suggests that it serves to reinstate information about the content and/or linguistic form of immediately preceding sentences. Local reviewing may, therefore, serve to reduce demands on STM. This hypothesis is consistent with findings from a recent eye-movement study that suggests that writers with low writing spans tend to read back more frequently than high-span writers (Alamargot, Dansac, Ros, & Chuy, in press). However Olive and Piolat (2002) found that preventing writers from reading back while producing short argumentative texts had no effect either on the quality of the finished text or on the fluency with which it was produced. They also found that writers who were prevented from reading responded more rapidly to probes presented during subsequent transcription. This suggests that reinstating information about sentences just written and holding this in STM may interfere with the production of the following sentence.

CONCLUSIONS

The idea that writing is a complex activity requiring the coordination of a variety of different cognitive processes, and that the cognitive overload that this can induce is a fundamental problem in writing, has been central to cognitive accounts of writing since their inception (see, for example, Flower & Hayes, 1980). In their original form, these models characterised writing in terms of a relatively low number of high-level processes, and subsequent research has typically employed a simple capacity model to explain how these processes competed for cognitive resources.

In this chapter we have argued for a less strategic model of how different processes are coordinated, and for a more dynamic model of the writing process and its interaction with short term memory. First, we have suggested that once one focuses on the more implicit and less accessible processes involved in text production (as opposed to the relatively explicit and accessible processes involved in problem solving) the range of processes involved expands enormously, as does the number of ways in which these processes might interact. This changes the way in which we conceptualise the writing system. We have argued that writing research needs to take account both of these complexities, and of the contentious nature of dominant models of working memory. Second, we have attempted to demonstrate that although conflict among writing processes can often be explained in terms of competition for a common resource pool, other accounts tend to have more explanatory power. Alternatives include explanations in terms of competition among concurrent processes for shared cognitive mechanisms (with retrieval from LTM perhaps representing a particularly pervasive bottleneck), in terms of interference between the outputs of different processes, and in terms of the problems associated with coordinating processes operating at different speeds. Third, consistent with most current accounts, we have suggested that working memory capacity is best viewed not as a fixed feature of individuals, but as dependent on task- and domain-specific memory management skills.

Finally, we have suggested that although some aspects of the writing process can be strategically controlled, others, such as the need to suppress irrelevant information or the need to re-read to refresh transient memory, arise as a consequence of a cycle of processing as it occurs on-line. In this context, the writer has no option but to adapt as flexibly as they can. No matter how skilled we are at managing the writing process, there is an irreducible core of potential conflicts. Writing will always be a struggle to reconcile competing demands. Writers have – motivationally – to accept this if they are to get the task done.

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