DEPARTMENT OF MANAGEMENT

Writers' Shift Between Error Correction and Sentence Composing: Competing Processes and the Executive Function

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Competing Processes and the Executive Function

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Abstract

Moment to moment, the skilled writer faces a myriad of potential issues. Different types of problem-solving compete for limited cognitive resources, with executive function presumably coordinating and thereby resolving this competition. In two experiments, we examined the coordination of two common writing tasks, editing and sentence composing. In Experiment 1, participants could approach the tasks in either order. For most items (88%), participants finished the sentence first, and less frequently (12%) corrected the error first. The error-first approach occurred significantly more often under the low-load condition than the high-load condition. For Experiment 2, we asked participants to adopt the less-preferred, error first approach. Success on completing the assigned task-order was affected by both factors, sentence load and error type. These results suggest executive function schedules tasks to mitigate direct competition over working memory resources.

Keywords: working memory, central executive, executive function, writing processes, proofreading.

Moment to moment, the skilled writer faces a myriad of potential issues. One set of problems arise from text production (e.g., “Is this the right word? How do I spell ‘recommend?’”) and another set from evaluation (e.g., “Will my reader understand this sentence? Should I correct this error now or later?”). Writers must somehow coordinate these disparate types of problem-solving.

Researchers use words like “recursive” and “interactive” to characterize the cognitive processing of more-skilled writers (Flower, 1989; Kellogg, 1987; McCutchen, 1996). Hayes and Flower (1980) observed that skilled writers tend to solve problems in an iterative fashion, rather than discretely or sequentially, and that any subprocess might interrupt another. This recursiveness suggests that skilled writers can flexibly address writing problems as they arise. In contrast, less-skilled and novice writers appear to adopt a more linear, noninteractive approach, which Bereiter and Scardamalia (1987) called knowledge telling. McCutchen (1996) attributed the noninteractive approach of novices to “capacity limitations caused by inefficient linguistic processing” (p. 305). To characterize the interactive approach sometimes adopted by more-skilled writers, Bereiter and Scardamalia (1987) used the term “knowledge transforming,” which they described as an interaction between the writer’s continuously developing knowledge and the continuously developing text. The authors proposed that more-skilled writers sometimes set for themselves relatively complex rhetorical and content goals, which give rise to more complex problems. In order to cope with complexity, the writer must somehow coordinate problem-solving, to address composing-related issues in an effective way.

In his review of the research literature, Kellogg (2008) concludes that highly-skilled writers are capable of:

> representing and manipulating three different representations in working memory. They do so by means of complex interactions among planning, generation, and reviewing that must be coordinated through executive attentional control (p. 11).

The processing of these various representations presupposes the availability of sufficient working memory (WM) resources, which in turn depends upon sufficient automaticity of certain basic writing processes. Although certain processes may become relatively automatized (e.g., spelling and handwriting/typing), drawing minimal load, others will necessarily remain processing intensive. Processing capacity must be allocated efficiently, so that one process does not interfere with another. One problem may be solved immediately, while another may be deferred or even ignored. How executive function resolves these conflicts—allocating scarce attentional resources for solving specific writing-related problems—is the central question of the present investigation.

Executive Function In Writing

In their model of working memory, Baddeley and Hitch (1974) proposed the central executive to account for the regulation and coordination of disparate cognitive mechanisms. Baddeley considers the central executive "certainly the most important component in terms of its general impact on cognition" (1996, p. 5). At the same time, he admitted that the original conception was rather vague, a "ragbag into which could be stuffed all the complex strategy selection, planning, and retrieval checking that clearly goes on when subjects perform even the apparently simply digit span task" (Baddeley, 1996, p. 6). As an essential executive function, Baddeley (1986) emphasizes the role of attentional control, suggesting parallels to Norman and Shallice's model (1986) of the Supervisory Attentional System (SAS). In explaining the SAS, Norman and Shallice (1986):

> assumed that external stimuli automatically activate well-learned action schemas. When several schemas compete for selection, a so-called contention-scheduling mechanism resolves this conflict. However, in situations in which a goal-specific schema must be selected against strong competition, contention scheduling is not sufficient, and voluntary or endogenous control is necessary. It is assumed that this type of control is exerted by a supervisory attentional system

(SAS) that affects the selection of schemas indirectly by biasing their activation (as summarized in Hübner, Futterer, & Steinhauser, 2001, p. p. 640).

Norman and Shallice point out that the SAS addresses the routine activation associated with coordinating subtasks, but leaves unexplained other functions attributed to the central executive, such as planning, decision making, and the solving of novel problems.

Executive function is posited to play a central role in models of skilled writing, (e.g., Flower & Hayes, 1980; Hayes & Flower, 1980; Kellogg, 1996). For example, Hayes and Flower (1980) proposed a "monitor" that controls how (a) editing and generating may interrupt other processes, (b) the writer's goals guide the coordination of processes, and (c) individual differences in goal-setting give rise to different writing profiles. To the extent that writing involves switching between multiple processes (Flower & Hayes, 1980), each cognitively demanding (Piolat, Roussey, Olive, & Farioli, 1996), executive function should play a highly important role in the cognition of writing. McCutchen (1996) has argued that excessive cognitive load (e.g., due to inefficient handwriting) can produce cascading effects that reduce writers' ability to coordinate other, higher-level processes, such as planning and reviewing.

Although many studies have implicated the importance of WM in writing (Bourdin & Fayol, 2000; Kellogg, 1999; Kellogg, 2001; Kellogg, Levy, & Ransdell, 1996; McCutchen, 1994; McCutchen, Covill, Hoyne, & Mildes, 1994; Piolat, Olive, & Kellogg, 2005; Piolat et al., 1996; Ransdell & Levy, 1996), few have specifically investigated executive function. Recent investigations shed light on how executive function may coordinate the processes of writing. Miyake, Friedman, Emerson, Witzki, and Howerter (2000) investigated the unity/diversity of executive function. In their study, undergraduates completed a battery of assessments, of which 9 specifically targeted one of the hypothesized functions, as well as 5 common measures of executive function. Confirmatory factor analysis revealed a three-factor model provided best fit the data, with a moderate correlation between factors. The three factors were interpreted as: mental set shifting, information updating, and inhibition. These three posited dimensions of executive function have clear relevance in explaining the dynamics of writing.

Task-switching.

One can easily grasp the importance of task-switching in writing. Early writing models (e.g., Hayes & Flower, 1980) recognized that one writing process may often interrupt another, as analysis of protocols revealed writers shifting between generating and organizing ideas, transcribing, reviewing, revising, and editing. As reflected in Norman and Shallice's SAS model, shifting may happen automatically or under strategic control. Since shifting depends upon attentional resources, the demands of one process might impede the capacity to shift to another process (McCutchen, 1996). Further, studies have repeatedly shown that switching between tasks involves a cognitive cost, as measured by task latency and accuracy (e.g., Jersild, 1927; Spector & Biederman, 1976). The cost of task-switching may serve to constrain the relative recursiveness of writing, such that a highly recursive approach to writing may depend upon highly automatized writing processes and the availability of sufficient working memory resources.

Updating information.

Updating information requires dynamically manipulating information (Lehto, 1996; Morris & Jones, 1990), and thus involves more than simply holding a representation in WM. It includes monitoring and coding incoming information, as well as using this new information to revise old information. Of the three executive functions, updating a mental representation appears most dependent upon working memory capacity (Jonides & Smith, 1997; Lehto, 1996).

Writing involves constructing and evaluating mental representations of language. The ability to manipulate these representations presupposes sufficient linguistic fluency and WM capacity. For example, more-skilled writers demonstrate greater fluency in sentence-generating and lexical-retrieval than low-skilled writers (McCutchen et al., 1994).

Inhibition.

Hedden and Yoon (2006) describe inhibition as the "suppression of unwanted or irrelevant representations, goals, and responses" (p. 512). At any given moment, a writer faces a host of potential composition-related problems, everything from generating content to detecting and correcting errors. While some writing processes may become relatively automatized (e.g., spelling and handwriting), drawing minimal resources, others may remain processing intensive. Competing for limited working memory resources, one process may interfere with another. Presumably, in order to focus limited attentional resources on a specific problem, writing requires overriding or inhibiting possible extraneous responses.

The following example illustrates the potential role of inhibition in writing. Suppose a writer notices (i.e., detects) an obvious typographical error while in the middle of composing a sentence. Does she correct it immediately or later? Detecting an error may activate a well-practiced schema for correction, but executing the schema will seemingly depend upon available resources. Correcting the error will more or less disrupt production, depending upon the nature of the error and the fluency of the writer. By inhibiting the correction response, executive function can keep the two processes from directly competing for resources, thereby mitigating the delitating effects of interference. In so doing, inhibition serves to effectively funnel scarce resources to one process, i.e., sentence composing.

Proofreading[1], an attention-demanding task.

Proofreading is a common activity for writers, since errors occur during text production. In their original framework, Hayes and Flower (1980) characterized editing as a process responsible for error detecting, which is triggered automatically, interrupting other writing processes. Recent conceptions do not distinguish between editing and reviewing, whether automatic or controlled. Rather, they emphasize the evaluative function, which can operate any time, either before, during, or after a sentence has hit the page (Hayes, 1996; Hayes, Flower, Schriver, Stratman, & Carey, 1987, p. 243; Kellogg, 1996).

Although seemingly trivial, proofreading is an attention-demanding task (Pilotti, Maxwell, & Chodorow, 2006). At the risk of stating the obvious, proofreading involves the application of reading skills to the problem of detecting errors. Accordingly, reading research provides insights into proofreading. For example, readers will spend less time processing (in terms of fixation duration) high frequency and predictable words (Ashby, Rayner, & Clifton, 2005) and are more likely to skip high frequency and short words (Drieghe, Rayner, & Pollatsek, 2005). It follows that errors located within high-frequency, predictable, short words may be more difficult to detect. Christianson, Johnson, and Rayner (2005) examined how transposing letters affected participants' ability to recognize words. They found that letters transposed across morphemes disrupted processing, while internal transpositions did not. For proofreading, this result suggests that within-morpheme errors may be detected less easily and less often. Collectively, the results of these studies suggest that default reading patterns may serve to render some errors more or less detectable.

Errors also differ in the type of processing required for their detection. Text errors that manifest as non-words tend to be more easily detected than contextually inappropriate real-words: The former (word-level errors) may be detected using word-level processing, whereas the latter (contextually

[1] We use the terms "proofreading" and "editing" interchangeably. Several studies have examined "proofreading," with participants finding and correcting errors in prepared texts. Since Hayes and Flower's (1980) model, writing researchers have used the term "editing" to refer to the process of the writer finding and correcting errors in her own text. Without dismissing the possibility of a "familiarity effect" (Carpenter), our focus is upon detecting and correcting errors.

inappropriate errors) can require semantic processing, to evaluate the text for internal inconsistencies (Hacker, 1994; 1997). The results of Laurigauderie, Gaonac'h, and Lacroix's (1998) proofreading study tend to support the idea that certain errors require more extensive processing. They found that errors requiring syntactic- and semantic-level analysis depended more strongly upon processing by the phonological loop and central executive, relative to detecting word-level errors. Since different types of errors require different levels of processing, proofreading requires "the strategic allocation of processing resources to different forms of information, i.e., orthographic, phonological, lexical, syntactic, and semantic" (Pilotti et al., 2006, p. 243).

EXPERIMENTS 1 & 2

In the following two experiments, we examined executive function in writing in terms of coordinating two common writing tasks, proofreading and sentence composing (i.e., arranging words into phrases). The design of the experiments was based on a study by Leijten (2007 Chapter 5). In her research she studied error correction strategies in an experimental setting in which writers had to complete a sentence (text production) and correct possible errors in the text produced so far (TPSF). By varying the type of error and the way in which the TPSF was presented, she tried to determine the relative contributions of cognitive effort from several sources, error span, input mode, and lexicality. In this paper we tested the hypothesis that strategies that "funnel central capacity to one or two processes, rather than many, should improve their functioning with regard to both effectiveness and rate" (Kellogg, 1996, p. 67). Participants were presented items consisting of a partial sentence, some of which included a single error. Participants were asked to (a) complete the sentence (using given target-words) and (b) to correct an embedded error. The dependent variable of interest was the order in which participants completed these subtasks. In Experiment 1, we examined whether aspects of the two tasks (i.e., the relative difficulty of the sentence-task or the nature of the error in the proofreading-task) influenced the order in which participants completed them. In Experiment 2, we assigned participants the less preferred task-order (first proofreading, then sentence completion), to examine the effects of the two factors (i.e., error type and sentence difficulty).

Method

Design and Materials

In earlier investigations of proofreading and editing, researchers have introduced errors into participants' previously written texts, then directed participants to find and correct those errors. While such an approach can provide evidence of participants' abilities to edit, it does not reveal how writers coordinate editing with other writing processes. We were particularly interested in how error detection and correction might influence sentence formulating, and vice versa.

We presented participants with partial sentences, which they were obliged to finish. Since domain knowledge is known to have a powerful influence on composing (McCutchen, 1986; Voss, Vesonder, & Spilich, 1980), we wanted to control the effects of planning. Similarly, since characteristics of the sentence could influence participant's ability to complete the item, we attempted to control salient text characteristics. Thus, each partial sentence: (a) referred to things and events in the general domain, (b) provided sufficient local context to identify the error, (c) contained the first clause of a complex clause with a connector, and (d) included 9-12 words.

Under normal conditions, the writer is familiar with her own text, which is the product of her own planning and formulating. In order to simulate the writer's familiarity with her own text, we used auditory priming. By hearing the partial sentence read-aloud, participants could begin to form a semantic and syntactic representation of the sentence, prior to seeing the target-words. We assessed the efficacy of this auditory priming in a pilot study (see below).

Participants were presented with either one or three target-words, by which we varied the cognitive demands of sentence composing (Fedorenko, Gibson, & Rohde, 2006). Participants were asked to use the target-word(s) to complete the sentence. These target-word(s) were topically related to the partial sentence, and were intended to provide content so as to minimize the need to generate ideas. See Table 1.

Table 1
Sample partial sentences with target word(s)

Partial sentence	One target word	Three target words
Het kleine meisje drukte haar knuffel hard tegen haar wang en ...	moeder	winkel, schreeuwen, moeder
De Beaujolais is een jonge wijn, die vroeg gebotteld wordt om …	smaak	fruit, behouden, smaak
Het schip lag voor anker in het midden van de haven, omdat …	vracht	graan, lossen, vracht

Each partial sentence contained a single word that could appear in one of three different error-conditions (which were counterbalanced across items, across participants): (1) correct word (no error), (2) orthographic near-neighbor error, or (3) orthographic far-neighbor error. Current generation writing tools, i.e., word processing and speech recognition, generally do not evoke non-word errors (e.g., “tpyos”). Consequently, we ensured that all errors were real-words. Near- and far-neighbor errors were constructed in relation to the correct word, sharing the same word class, number of syllables (i.e, two or three), and similar word frequency. Errors deviated from correct words according to internal graphemes (in the onset of the unstressed syllable): with (a) near-neighbors deviating only one phoneme and one or two graphemes and (b) far-neighbors deviating by two phonemes and more than two graphemes. Within the partial sentence, errors were located internally, never as the first or last words, and equally distributed between nouns and verbs. Thus, errors filled the same syntactic role as the correct words—while being semantically at odds with the context of the partial sentence. See Table 2.

Table 2

Sample partial sentences with three types of embedded errors

Correct word (no error)	Orthograpic near-neighbor error	Orthographic far-neighbor error
Het kleine meisje drukte haar **knuffel** hard tegen haar wang en ...	Het kleine meisje drukte haar **knuppel** hard tegen haar wang en ...	Het kleine meisje drukte haar **kronkel** hard tegen haar wang en ...
De Beaujolais is een jonge wijn, die vroeg **gebotteld** wordt om …	De Beaujolais is een jonge wijn, die vroeg **geborreld** wordt om …	De Beaujolais is een jonge wijn, die vroeg **gebengeld** wordt om …
Het schip lag voor **anker** in het midden van de haven, omdat …	Het schip lag voor **anjer** in het midden van de haven, omdat …	Het schip lag voor **karper** in het midden van de haven, omdat …

Approximately 50% of partial sentences contained either a near- or far-neighbor error. Participants encountered the partial sentences in the same order, while the two conditions (i.e., number of target-words and type of error) were counterbalanced across participants.

Apparatus & Procedure

Data was collected from each participant individually in a single session of approximately 1 h. All materials were presented in Dutch. Throughout the session, the participant wore audio headphones while seated approximately 81 cm before a PC monitor and keyboard.

A custom designed PC program, written in .NET, administered the experimental items, which involved coordinating two subtasks, (a) sentence completion and (b) error detection/correction. The procedure was designed to simulate conditions writers typically encounter during drafting. As a writer formulates his or her thoughts into sentences, errors can occur during inscribing. The writer may or may not detect the occurrence of an error. When an error is detected, the writer may or may not correct it immediately.

Each experimental item consisted of four screens, presented sequentially:

1. An opening screen, which the participant clicks to begin the item
2. A blank screen, during which the first part of a complex sentence is read aloud (auditory priming), then repeated.

3. One or three target-word(s) are displayed (in a line, separated by commas) at the bottom of the screen, for 1 s and 3 s, respectively. Participants were instructed to memorize these words.
4. The text-version of the partial sentence (as read aloud in screen 2) is now displayed on the screen, which may include an error. Participants were directed to use the keyboard and mouse to:
    a. Correct the error (if present)
    b. Complete the sentence, using the all the target-words (either 1 or 3) displayed on screen 3.

    Note: In Experiment 1, participants were allowed to complete tasks (a) and (b) in either order, whereas in Experiment 2, they were asked to correct the error first.

In preparation for the experimental items, participants viewed a short (30 s) video demonstrating an experimental item, along with instructions. After completing four practice items, the participants began the 42 experimental items. Participants were directed to work quickly and accurately.

To evaluate whether audio priming actually facilitated both sentence composing and error correction, we pilot tested these items, apparatus, and procedures on 28 undergraduate students at a Belgium university. The items were presented to participants, according to the procedure described above, with one alteration: One half (21 items) were presented with audio priming, and the other half (21 items) without audio priming. The results showed that auditory priming significantly improved participants' overall performance on the items, in terms of successfully completing the sentences (using the target-word(s)), successfully correcting errors, and reducing the average time on each item. The results of this pilot test suggest that this audio priming provided the desired facilitating effect, and so could serve to simulate the familiarity one might have in composing her own text.

EXPERIMENT 1

Writing tends to unfold in a series of tasks. The writer stops to plan the next sentence, drafts a clause, notices a spelling error, fixes it, plans the next clause, and so forth. Presumably, this sequential scheduling minimizes concurrent processing, mitigating potential interference by distributing processing demands over time. Much evidence indicates that the high demands of one process can interfere with the function of another. For example, the notion of interference may be helpful in understanding how the demands of handwriting can impair the function of lexical retrieval (Bourdin & Fayol, 2000). Viewed in this way, writing competency involves mechanisms and/or schema for coordinating a series of processes, beginning with generating an idea, mapping language onto it, transcribing it, and checking for accuracy. When two writing subtasks compete for selection, how does executive function resolve the conflict?

In Experiment 1, we examined executive function in terms of task scheduling, the order in which writers coordinate two common writing tasks (i.e., editing and sentence composing). In this experiment, participants were free to complete the two tasks in either order. Given the load associated with holding target-word(s) in working memory, we hypothesized that participants would tend to complete the sentence first (in order to discharge the load from working memory), then proceed to correct the error.

Method

Participants

Forty one undergraduate and graduate students (16 male, 23 female) at a Netherlands university participated in the study (male / female). All participants were native Dutch speakers, who received € 7.50 for participating.

Apparatus & Procedure

This experiment followed the procedure (as described above), except that participants were instructed to complete the two subtasks in either order, according to personal preference.

Results and Discussion

We used ANOVA to evaluate the effects of the factors on the dependent measures.

Target-word score. A main effect revealed that participants were significantly more successful in the integration of one target-word (M = . 99), relative to three target-words (M = .93), $F(1, 42) = 22.44$, $p = .000$.

Start time. A marginally significant main effect for Target-words, $F(1, 42) = 3.74$, $p = .06$, suggests that participants spend longer prewriting time when integrating one target-word (M = 13.70 s), relative to three target-word(s) (M = 13.04 s).

Production time. Participants spent significantly longer when integrating three target-words (M = 16.88 s), relative to one target-word (M = 14.30 s), $F(1, 42) = 81.10$, $p = .000$. Also, Error-type influenced the overall time to complete the task, $F(2, 84) = 75.58$, $p = .000$. The post hoc analysis indicated that overall task time was significantly longer when it involved correcting orthographic far-neighbor errors (M = 17.42), relative to near-neighbor errors (M = 15.69 s, $p = .000$), which in turn took longer than no-errors (M = 13.65 s, $p = .000$).

Task-order. In this experiment, participants were free to choose the order in which they completed the tasks of error-correcting and sentence-completing. For most items (88%), participants finished the sentence first, and less frequently (12%) corrected the error first. By completing the sentence first, participants freed themselves from the load of keeping the target-word(s) active in working memory, which allowed them to proceed to error correction unencumbered. However, participants sometimes opted to correct the error first. A main effect for Target-words indicated that participants more frequently opted to correct the error first when asked to use one target-word (M = .13), relative to three target-words (M = .07), $F(1, 31) = 11.09$, $p = .002$.

No other differences proved reliable.

Cognitive load apparently influenced participants' approach to the error correction / sentence completion task. Participants most often adopted the finish-sentence/correct error approach. This is an efficient approach, since finishing the sentence (i.e., putting the target-words into a clause or phrase) immediately relieves the load upon WM, which frees resources and forestalls the chance of forgetting. Further, the sentence-first approach is efficient because the participant may happen to detect the error while in the act of finishing the sentence.

Participants rarely adopted the error-first approach. However, when they did, it occurred significantly more often under the low-load (one target-word) than the high-load (three target-words) condition. This result suggests that a low-load during sentence composing (i.e., remembering one word) leaves sufficient WM resources available, allowing for more flexibility in problem-solving.

EXPERIMENT 2

The results of Experiment 1 indicated that participants generally deferred error correction, perhaps to better manage the demands of problem-solving. Participants were more likely to correct the error first when the demands of sentence composing were low. Notably, the type of error did not appear to affect participants' ability to complete the sentence; nor did the complexity of the sentence composing task influence their success in correcting errors. Participants were generally able to successfully carry out the two tasks, given the flexibility in using whichever approach they preferred. This leaves open the possibility that executive function schedules tasks to manage the competing demands.

In Experiment 2 we tested this hypothesis, by asking participants to adopt the less-preferred (in Exp. 1) approach, i.e., finding and correcting errors before completing the sentence. We hypothesized that this error-first approach, by focusing participants on error correcting, would degrade their performance on sentence composing.

Method

Participants

20 native speakers of Dutch (11 female, 9 male), all of them students at a Belgian university, took part in the experiment. The mean age was 21.75 (SD = 1.8). Participants received a gift voucher (€ 5).

Apparatus & Procedure

This experiment followed the same procedure as Exp. 1, with one important change: Participants were asked to first correct the error (if present), then complete the sentence.

Results and Discussion

Target-word(s) score. In the integration of target-word(s) into their sentences, participants were significantly more successful with one word ($M = .97$) than three words ($M = .82$), $F(1, 19) = 24.37$, $p = .000$.

Production time. In the analysis of production time, participants not surprisingly spent significantly longer when integrating three target-words ($M = 17.74$ s), relative to one target-word ($M = 14.92$ s), $F(1, 18) = 23.26$, $p = .000$. Also, a second main effect indicated that the type of error influenced the overall time to complete the task, $F(2, 36) = 16.10$, $p = .000$. The post hoc analysis indicated that correcting orthographic far-neighbor errors took significantly longer than near-neighbor errors ($M = 17.81$ s, $p = .007$), both of which took longer than no-errors ($M = 14.77$ s, $p = .019$).

Task order. Participants were asked to correct errors first, before finishing the sentence, but they did not always do so. In some cases, participants apparently failed to detect the error on the first scan of the sentence, so proceeded to complete the sentence; only then did they notice the error, which they then corrected. Two main affects indicated that success in correcting the error first was influenced by both factors. Participants more often went to the error first, as required: when juggling only one target-word (M = .85), relative to three target-words (M = .80), F(1, 19) = 4.48, p = .05; and when confronted by orthographic far-neighbor errors (M = .86), relative to near-neighbor errors, (M = .79), F(1, 19) = 10.12, p = .01.

No other differences proved reliable.

In Experiment 2, we asked participants to adopt the less preferred approach, i.e., finding and correcting the error ***before*** finishing the sentence. However, participants often (in 15-20% of the items) finished the sentence first, then corrected the error afterward. In these failures to carry out the assigned approach, it is reasonable to assume something like the following scenario: The participant quickly scans the partial sentence, fails to detect an error, proceeds to complete the sentence (so as to not forget the target-words)—only then notices the error and corrects it.

Both factors (i.e., error-type and composing-load) affected the participants' ability to successfully carry out the assigned task order. Interestingly, imposing the less-preferred approach did not result in significantly degraded performance, either in error-correcting or sentence-composing. These results allow the following interpretation. The cognitive load associated with holding the three words in working memory (i.e., updating information) interferes with participants' ability to detect errors, especially the more subtle errors. Further, if the participant does not complete the sentence relatively quickly, she may forget the target-word(s). Thus, limitations in working memory processing may creates a type of urgency. In Experiment 2, participants almost always used the correct target-word(s), suggesting that they tended to shift toward sentence completion before actually forgetting a target-word(s). In the competition between error detecting/correcting and sentence completion, there may be some bias toward the latter, especially since only some sentences (50%) actually had an error.

In addition to cognitive load, the nature of the error (either orthographic near- or far-neighbors) also appeared to play a role in the switch to sentence completion. More subtle (Near-neighbor) errors were less easily detected, and participants may have given up the search prematurely, especially since not all sentences included an error. From the participants' perspective, all items required completing a sentence, but only some (50%) had an error to fix. Further, participants' ability to hold three target-words in WM is rather limited; at some point, forgetting will occur, which will reduce their ability to successfully complete the sentence. At some point, the participant decides that there is no error and proceeds to complete the sentence.

General Discussion

The act of writing requires the coordination of multiple processes, with executive function presumably managing this coordination. In order to investigate the dynamics of composing, the present investigation focused upon the coordination of two common subskills, sentence-composing and proofreading. To simulate text production, the *sine qua non* of writing, we presented participants with a cloze task which involved finishing a sentence. This cloze task was presumably time sensitive, since participants needed to complete the sentence before they forgot the target word(s). Editing is also a fact of life for writers, since writing tools and their users make mistakes. Part of the writers' job is finding and correcting errors of orthography, grammar, or punctuation—should they occur. Participants were presented with partial sentences, some of which contained a single error, and were asked to correct the error. We designed the text production and proofreading tasks to be distinct, requiring participants to complete them sequentially. Interestingly, neither of the two factors (i.e., word-load or error-type) appeared to significantly influence the accuracy of task completion. Participants were generally able to complete the sentence and correct the embedded errors. The order of task completion became the focus of our interest.

When participants were free to complete the two tasks in either order (Exp. 1), they almost always opted to complete the sentence first. This approach makes sense, because it offers a certain efficiencies. It offers immediate relief of cognitive load, freeing attentional resources for proofreading. Further, in the process of finishing the sentence an error may be serendipitously be detected. On a small minority of items, participants opted to correct the error first, which occurred more frequently when holding one word (versus three words) in WM. Apparently, remembering one word left sufficient resources available for proofreading. These results suggest that available WM resources affords flexibility in task-scheduling.

In Experiment 2, we attempted to induce a scheduling conflict, to examine how executive function resolved it. By asking participants to correct the error *before* completing the sentence, both tasks become time sensitive. The results showed that participants were less able to follow this error-first approach (as directed) when either the load of text production was high (i.e., using 3 words) or errors were subtle (i.e., near-neighbor errors). The effect for error type appears relatively straight-forward. Participants do a quick scan for errors, fail to detect a detect a subtle (near-neighbor) error, assume there is no error, proceed to complete the sentence—then discover the error and correct it. There are at least two possible explanations, which are not mutually exclusive. It is possible that that the participant wished to avoid forgetting the target-words, so rushed from proofreading to complete the sentence. It is also possible that holding target words in WM degrading the performance of proofreading, by drawing off attentional resources. Once the sentence was completed, attentional resources became available and proofreading efficacy returned; only then did the participant detect the error and correct it. The present results suggest that editing processes (error detecting and correcting) compete with text generating processes for limited attentional resources, with editing processes “seizing” attentional resources when they become available.

The results Experiments 1 and 2 suggest that executive function schedules tasks to minimize one interfering with another. WM capacity imposes limits on concurrent processing, which executive function partially resolves by scheduling tasks sequentially, to avoid direct competition for resources. Some sequences heighten the possibility of competition, and thus interference. When participants attempted to correct the error before completing the sentence (as directed in Exp. 2), a certain amount of concurrent processing was required. That is, they were obliged to detect and correct errors (i.e., proofread) while the target word representations active in WM. Interestingly, the two factors did not appear to significantly affect the speed or accuracy of participants’ responses, although they did appear to influence participants’ ability to accomplish the assigned task order. Participants were less successful accomplishing the error-first approach, when either the sentence-task was complex (i.e., 3 target-words) or the errors were subtle (i.e., orthographic near-neighbors). Notwithstanding, participants often returned to correct an error after completing the sentence.

Thus, although we assigned a rigid, linear approach, the dynamics of participants’ writing behavior still often emerges as flexible and recursive. In competing for limited WM resources, processes also compete for processing time. Some writing tasks are processing-intensive, e.g., finding a subtle error may require processing semantic, syntactic, and lexical information. Others are time-sensitive, i.e., when a writer has certain words “in her head,” she must write them down before she forgets them. The results of this study suggest that a writer may deal with writing tasks in a flexible manner, when sufficient WM resources are available. However, when resources are less available, shifting between tasks becomes necessary. This shifting appears to be automatic, rather than strategic. Thus, the dynamics of composing appear to reflect the allocation of processing resources: Executive function shifts between tasks, to accommodate their various processing needs, essentially scheduling processing time for each. This explanation is consistent with Norman and Shallice's (1986) SAS model.

The results do not speak to the deeper questions of executive function. How does the central executive "know" when to shift? What role do goals play in this shifting? Connectionist research provides interesting evidence of how complex processing can emerge from simple processing mechanisms. The present results do suggest that executive function may shift tasks to avoid direct competition over resources, in accordance with task goals. Writing involves a complex potential variety of tasks, and the challenge to the central executive is to coordinate these tasks effectively, to maximize performance within the limits of WM. A "simple mechanism" underlying executive function might account for much.

The educational implications of these results align with some prominent practices in writing instruction. In particular, the "process approach" tends to structure the writing process, so that students can focus attentional resources on specific types of problem-solving. Students learn to view writing as an activity composed of a variety of stages, i.e., prewriting, drafting, revising, and editing (Olson, 1999). The process approach models a sequencing of tasks, which to some extent isolates one type of problem-solving from another. In so doing, the process approach may serve to minimize the effects of interference. In addition to minimizing conflicts between different types of writing tasks, isolating problem solving provides an opportunity for instruction. In the process approach, language arts teachers can instruct students in the use of strategies for planning, drafting, and revising, which has proven highly effective in improving students' writing skills (Graham & Perin, 2007).

Different approaches to writing instruction instantiate this principle (i.e., minimizing the influence of interference) in somewhat different ways. For example, in contrast to the process approach, Elbow (1973, 1981) advocates a dual draft approach, characterized by fluent, unfettered drafting, followed by extensive revising. According to Elbow (1981), "Writing calls on two skills that are so different that they usually conflict with each other: creating and criticizing. . . . It is true that these opposite mental processes can go on at the same time" (p. 7). His dual draft approach serves to minimize task conflict by to some extent separating "creating" from "criticizing." Both the process approach and dual draft approach effectively organize the writers' time during the writing session, so as to somewhat isolate one type of problem solving from another.

The results of the present study have some limitations. First, to investigate executive function, we employed a rather artificial writing task, and it is not clear how the results may or may not generalize to more authentic types of writing tasks. Second, our sample included university undergraduates (i.e., more-skilled writers), and it remains uncertain how the results might apply to novice or struggling writers. These latter populations are of particular interest, since many children do not develop mastery in writing skill (e.g., in the United States, see Salahu-Din, Persky, Miller, & National Center for Education Statistics, 2008). The results of the present investigation suggest that writing skill involves the ability to smoothly coordinate writing subtasks, so as to minimize the disruptive influence of interference. How children develop this ability becomes an important question for the development of children's writing skills, with implications for writing instruction.

Conclusion

Writing is a complex skill that takes many years to master (Kellogg, 2008). Although executive function figures prominently in conceptions of writing competency, its role remains poorly understood. The present investigation examined how executive function coordinates the scheduling of writing subtasks, which manifests as the temporal dynamics of composing. The results suggest that an important role executive function is minimizing interference, by generally scheduling tasks to avoid direct competition over limited attentional resources. When certain writing tasks demand more extensive processing, minimizing inference may be crucial to avoid degraded performance. The need to minimize interference may have an overriding effect, imposing a more "rigid" scheduling of tasks. In contrast, minimizing interference may be less crucial when “easier” writing tasks need not compete for limited resources, which allows for more flexible scheduling.

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