Chapter 7

Verbal and Visual Working Memory in Written Sentence Production

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During written sentence production, semantic content is planned and then encoded into a linguistic expression. Verbal working memory may enable these required computations by temporarily storing word representations. By contrast, visual working memory may only be needed when the semantic content activates imaginal as well as prepositional codes. College students wrote in longhand definitions of either concrete or abstract nouns, while concurrently performing either a visual or verbal working memory task. Both concrete and abstract nouns would disrupt the verbal task, but only concrete nouns would disrupt the visual task. The definitions were richer in detail for the concrete words, suggesting imagery was involved, compared to the abstract words. As predicted, only these image-evoking words slowed reaction times on the visual working memory task compared to baseline, control measurements. Both high and low imagery words interfered equally with the verbal working memory task. The results are discussed in terms of planning and translating ideas and processes involved in sentence generation.

7.1. Introduction

Working memory refers to a system for temporarily maintaining mental representations that are relevant to the performance of a cognitive task in an activated state. There have been a wide range of theoretical approaches to working memory proposed in the literature (Miyake & Shah, 1999), but in the present chapter we adopt the view that working memory comprises multiple components. The original Baddeley (1986) model postulated a phonological loop for storing and rehearsing verbal representations, a visuo-spatial sketchpad for visual object representations and their locations, and a central executive for attentional and supervisory functions. The evidence to date suggests that the visual and spatial components are distinct from one another and that the phonologically based verbal store is separate from

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a fourth semantic store (e.g., Jonides & Smith, 1997; Haarmann, Cameron, & Ruchkin, 2002; Martin, Shelton, & Yaffee, 1994). In writing, the central executive may be the most important component because it appears to be involved in planning ideas, translating ideas into text, and reviewing the ideas and text produced thus far (Kellogg, 1996). Only motor transcription operates effectively with minimal or no executive attention and this is true only when handwriting or typing is well practiced and automatized in adults. For young children, the attentional demands of even handwriting are a major impediment to fluent and effective composition (McCutchen, 1996). When motor transcription is laborious, the central executive and possibly other components of working memory are diverted from planning, text generation, and reviewing (Bourdin & Fayol, 1994; Olive & Kellogg, 2002). A psychometric study of individual differences in children's working memory indicated that only measures related to executive functions in the verbal domain accounted for a large source of variance in compositional quality and fluency (Swanson & Berninger, 1996).

What, then, might the roles be for the other components of working memory in text production? The role of verbal working memory in sentence comprehension has been extensively investigated (e.g., Caplan & Waters, 1999; Just & Carpenter, 1992). Because of the difficulties involved in studying production (Bock, 1996), it is not surprising that less is known about the working memory requirements of sentence generation and writing extended texts. For spoken sentence generation, it is necessary to translate the conceptual contents of the message to be communicated into a grammatically correct string of words and encode these words phonologically (Bock & Levelt, 1994). Is grammatical encoding modular or is it dependent on the general cognitive resources of working memory? For written sentences, there must also be a stage of orthographic encoding to spell each word. Phonological encoding may also be involved in written sentence production, because one route to word spelling is a conversion of phonemes to graphemes (Caramazza, 1991). Are the grammatical, phonological and orthographic encoding stages required in written sentence generation limited by the availability of working memory? What are the working memory demands of planning the conceptual content before it is translated into a sentence?

In the present chapter, we seek to take a preliminary step in addressing these fundamental, unanswered questions. Specifically, we tested the hypothesis that one or more aspects of translating the conceptual content of a sentence into a well-formed linguistic structure requires verbal working memory. It is not possible with our procedures to isolate the individual demands of grammatical, phonological, and orthographic encoding. Rather, we sought to measure whether all three of these taken together required verbal working memory. We further tested the hypothesis that the visual component of working memory is involved in planning the conceptual content of a sentence when the writer manipulates images of objects and events. Thus, our focus is on distinguishing between the working demands of planning conceptual content, on the one hand, and translating this content into a linguistic expression, on the other.

7.1.1. Background

A model of sentence generation: Sentence generation entails planning conceptual content and then linguistically encoding it into a grammatical string of words. Imaginal and propositional representations are translated into the ordered words of a sentence through grammatical and phonological encoding. Grammatical encoding includes functional processing, in which lexical entries are selected and their semantic-syntactic functions assigned, and positional processing, in which the lexical forms are retrieved and the sentence constituents assembled (Bock & Levelt, 1994). Orthographic encoding is further needed in written production prior to handwritten or typed motor output (Carramaza, 1991). Unlike spoken production, spelling is required for written production. Phonological encoding appears to provide one route for determining the needed graphemes, whereas another route is based on lexical-orthographic representations (Badecker, Hillis, & Caramazza, 1990).

Verbal working memory: Power's (1985) results first suggested that a heavy load on verbal working memory reduces slightly the length of generated sentences. He studied spoken production while participants concurrently retained either three or six digits in verbal working memory. The six digit, but not the three digit, load tended to shorten sentence length, but the effect was weak and proved reliable only in a materials' analysis of variance and not in the subjects' analysis.

Sentence length was reliably reduced by a six digit concurrent load in a text production task (Ransdell, Levy, & Kellogg, 2002), however. Participants were interrupted as they wrote short essays to encode and later to recall sets of six digits. Repeated sets were studied and then tested throughout the writing session. The average sentence length was reduced from 12 words in the control to 8 words in the six-digit condition. By contrast, a light load on verbal working memory in the form of irrelevant speech has little, if any, effect on sentence length.

The sentence length effect might imply that verbal working memory is essential for unimpeded sentence generation, at least in written if not spoken output. When verbal working memory is distracted by the requirement to encode and retain six digits, then fewer words per sentence are possible. It is unclear, however, if the sentence length effect is due to the loading of verbal working memory or other components of the system. For example, it might be argued that attentional and other executive functions were solely responsible because coordinating two tasks requires the central executive (D'Esposito et al., 1995). To resolve this issue, Kellogg (2004) modified the task designed by Power (1985).

At the start of each trial, participants received two noun prompts to include in each sentence. As in Power's experiment, either a moderate or heavy load was placed on verbal working memory by requiring the retention of either three or six digits during sentence production (Baddeley & Hitch, 1974). As an additional condition, the visual and spatial components of working memory were loaded by requiring the retention of a visual image in order to decide if a probe coincided with a part of this image (Podgorny & Shepard, 1978). All dual task conditions demanded executive functions of working memory but they differed in the demands placed on the verbal versus visual and spatial components. If sentence length is reduced only in the digit conditions, then it can be concluded that verbal working memory is necessary for unimpeded sentence generation.

In two experiments, the sentences generated while maintaining six digits in working memory contained reliably fewer words than those generated under no load, a visual-spatial load, and a three-digit load. A half word reduction was observed. This matched the findings of Power's results with spoken production, where six digits allowed fewer words per sentence ($M = 7.25$) than did a no load control ($M = 7.75$). A load of three digits produced a small, unreliable reduction in both the spoken and written experiments.

The sentence length effect appears to be a result of the heavy demands placed on verbal working memory by the concurrent retention of six digits. A less extreme load on verbal working memory and a load on the visual and spatial components of working memory did not reliably shorten sentence length, despite their demands on executive functions (D'Esposito et al., 1995). If all three load tasks placed equal demands on attention and other functions of the central executive, it could be concluded that verbal working memory is the critical resource needed for normal sentence length. On the other hand, it could also be argued that the six-digit condition recruited more executive attention to rehearse the digits because they exceeded the four-item capacity of the verbal store (Cowan, 2000). Thus, the safest conclusion from these results is that the sentence length effect was caused by an increase in demands on both the executive and verbal components of working memory in the six-digit condition (see also Ransdell et al., 2002).

A six-digit load seems to target sentence length precisely without affecting other linguistic features. Just as many clauses were generated while retaining six digits as with none when complex sentences were requested by the experimenter. Neither grammatical nor spelling errors were impacted. Reading level, vocabulary complexity, sentence complexity, and use of passive constructions were all the same for a no load as for a six-digit load. It could well be argued from these null effects that sentence generation is largely automatic and modular. The cognitive resources of working memory were, for the most part, unnecessary to plan, encode, and execute a single written sentence. But for the persistent reduction in sentence length, when the load on verbal working memory was great, the modularity hypothesis accounts for the data.

An important boundary condition of this finding is that each sentence was generated in isolation from the next. In text production, there must be coherence among sentences and the working memory demands would be greater than in isolated sentence generation. Accordingly, Ransdell et al. (2002) found that six digits held in working memory disrupted the subjectively rated quality of the essays written in addition to sentence length. Thus, the production of a coherent extended text is highly unlikely to be modular, as argued by McCutchen (1984, 1988).

Planning versus translating: The locus of the sentence length effect is unclear. One might argue that a concurrent load of six digits disrupts the planning of conceptual content or the translation of content into sentences. Planning produces abstract propositions and images that must be encoded linguistically. This translation process entails grammatical, phonological, and orthographic encoding. If one assumed that the six-digit load disrupted only the planning of content, then it could be argued that the linguistic processes involved in generating an isolated sentence are indeed modular. If fewer propositions were retrieved or generated before initiating the sentence, then grammatical and perhaps subsequent stages of encoding might be automatic but a reduction in sentence length and typing time would be observed nonetheless.

It should be noted that abstract propositions are presumably maintained in semantic working memory (Martin et al., 1994) and concrete images in visual working memory (Sadowski & Paivio, 2001). To trace the sentence length effect to planning, one must assume that the six-digit load disrupted semantic working memory instead of or in addition to verbal working memory. This hypothesis could be tested by manipulating the meaningfulness of the concurrent task. Six meaningful nouns should reduce sentence length, whereas six nonsense syllables should not.

One aspect of Kellogg's (2004) findings suggest that planning is not the culprit in the sentence length effect, however. Electrophysiological recordings have revealed that the comprehension of sentences containing three unrelated nouns activates brain regions subserving semantic working memory to a greater degree than those containing three related nouns (Haarmann et al., 2002). It takes more time to initiate sentence production for two unrelated noun prompts that are weakly activated in semantic working memory compared to two related nouns (Power, 1985; Rosenberg, 1977). This relatedness effect ought to increase under a six-digit load condition on the assumption that the concurrent retention of six digits disrupts planning. But Kellogg's (2004) results showed that the difference in initiation time between related and unrelated prompts was no greater under a six-digit load than in a no-load control. Despite reasonably large sample sizes ($N = 48$ in Experiment 1 and $N = 72$ in Experiment 2), the relatedness effect remained stable across the load conditions.

Thus, it appears that some aspect of linguistic encoding rather than planning is disrupted by a six-digit load. This interpretation corroborates the finding that grammatical encoding can be disrupted by a heavy concurrent load on working memory. Fayol, Largy, and Lemaire (1994) reported that maintaining five words in working memory can cause subject-verb agreement errors in the written transcription of orally presented French sentences. Errors occur under memory load when verb agreement depends entirely on orthography, but are markedly reduced when phonological cues are available (Largy & Fayol, 2001). Individual differences in the capacity of verbal working memory as measured by reading span and skill in lexical selection and retrieval are also reliably correlated (Daneman & Green, 1986; McCutchen, Covill, Hoyne, & Mildes, 1994). Such relationships should not be observed if linguistic encoding is entirely modular and not dependent upon verbal working memory.

Visual working memory: It has been argued thus far that verbal working memory probably supports one or more aspects of linguistic encoding rather than the planning of conceptual content. What about the visual and spatial components of working memory? Kellogg (1996) proposed that these components might play a limited role in text production. Specifically, generating concrete ideas would invoke visual imagery and organizing ideas would invoke arranging them spatially (Sadowski & Paivio, 2001).

Some evidence supports the view that visual and spatial working memory plays a more limited role in text production than does verbal working memory. In a text production task Lea and Levy (1999) found that a concurrent visual-spatial tracking task in fact disrupted the fluency of written composition by 13% relative to a writing only control condition. A concurrent phonological task disrupted fluency still more (21%) and showed more task errors compared to performance on the visual-spatial task. Swanson and Berninger's (1996) concluded that individual differences in the capacity of visual-spatial working memory fail to correlate with children's writing performance, whereas they do so with their reading performance. Also, Kellogg's (2004) visual-spatial load on working memory failed to shorten length reliably whereas a heavy load on verbal working memory did so.

Still, none of these previous studies directly tests the hypothesis that visual working memory is only needed for planning ideas in the form of concrete images. Further, it remains uncertain whether the disruptions in sentence production obtained when a heavy load is placed on verbal working memory are not at least partly attributable to the central executive. Retaining six digits (Kellogg, 2004) or five words (Fayol et al., 1994) while writing a sentence could place a heavy load on both the central executive and the verbal component of working memory. An experiment designed to address these issues is needed.

7.1.2. Rationale

The roles of verbal and visual working memory in the written production of a single sentence were examined in the experiment reported here. Participants wrote in longhand definitions of either concrete or abstract nouns, while concurrently performing a task demanding either visual or verbal working memory. The visual and verbal versions of the task were designed so to equate the demands made on the central executive. We predicted that defining both concrete and abstract nouns would disrupt the verbal task, but only concrete nouns would disrupt the visual task. An interaction of task and materials would rule out the view that the verbal interference is caused by diverting the central executive from writing. If that were so, then the concrete and abstract nouns ought to disrupt equally the visual task, too. The predicted interaction, therefore, would support the hypothesis that verbal working memory per se is necessary for linguistically encoding the content of any sentence, whereas visual working memory is needed only in planning sentences with concrete nouns.

Sadowski, Kealy, Goetz, & Paivio (1997) argued that writing definitions of concrete words draws on imaginal as well as propositional representations. In support of this claim, they reported that participants initiate production faster and compose more detailed, higher quality definitions of concrete compared with abstract nouns. Further, they reported using imagery more often in defining concrete relative to abstract words. Here we sought to replicate their findings and extend them by including verbal and visual concurrent tasks.

Participants composed definitions while concurrently performing a working memory task designed to require either the verbal or the visual component, plus the executive functions demanded in juggling the task concurrently with writing (D'Esposito et al., 1995). It was predicted that in composing definitions of only high imagery, concrete words would interfere with a visual working memory task. Because the maintenance of word representations was hypothesized to be necessary in linguistically encoding any written sentence, we expected that both low and high imagery words would disrupt the verbal working memory task.

The verbal working memory task required detecting visually presented phonological segments (ba or da) on a 30 s variable interval schedule and deciding rapidly if the stimulus matched the last one presented. In reading these stimuli, phonological representations are known to be activated as well as orthographic representations (Massaro & Cohen, 1994). It was desirable to equate the verbal and visual tasks with respect to presentation modality, varying only the kind of materials used, so that the phonological segments were read rather than heard. The visual working memory task was identical to the verbal task, except that objects (triangle or circle) instead of phonological segments were presented.

The secondary task of tone detection provides a measure of the executive attention required by writing (Kellogg, 2004). Here, the secondary task required more than detecting a stimulus, focusing attention on it, and scheduling a response. It was also necessary to store the stimuli and update the contents of either verbal or visual working memory. The two tasks were expected to be equally difficult to perform under baseline conditions, assuming that each makes the same demands on the central executive. Thus, any differences observed under dual task conditions should be attributed to the effects that writing has on the verbal versus visual stores themselves.

7.2. Method

College students (N = 60) were assigned in equal numbers to one of four groups defined by the factorial combination of materials (concrete versus abstract nouns) and tasks (verbal versus visual). In each condition, participants wrote definitions of 10 nouns while concurrently performing a working memory task that required the detection of a visually presented target and a speeded decision regarding whether to respond. They were instructed to respond by clicking a mouse button whenever the target was different from the last one presented. Thus, the task required maintaining the most recent target in working memory, detecting a new target, matching the new target to the one in memory, deciding to respond or to inhibit responding, and updating the most recent target. Reaction time (RT) was measured in ms along with the percentage of correctly detected targets. The instructions and stimuli were presented with a modified version of SCRIPTKELL (Piolat, Olive, Roussey, Thunin, & Ziegler, 1999).

For the verbal working memory task, each target consisted of a pair of phonological segments (ba and da). On a 30 s variable interval schedule, one of the two targets appeared in large letters on a computer screen. The screen was below a glass desktop on which the participants wrote the definitions on paper in longhand using their dominant hand. The mouse was positioned near their non-dominant hand for responding to each non-repetition target. Thus, in the sequence ba ba da ba, the participant was instructed to respond to da and the final ba. For the visual working memory task the same procedure was followed, but the materials were large visual shapes (triangle or circle).

Baseline measurements were collected for the working memory task in isolation, so that the degree of interference in RT could be determined. Also, the definition task was performed as a control condition without the concurrent task for 10 min. The data were collected in three blocks. The procedure began with the working memory control block for 12 min., followed by the definition control block for 10 min. Extra time was given for the working memory task to insure it was adequately learned. Finally, the dual task condition was tested for 10 min. The instructions for each condition were read on the computer screen before beginning each block.

A total of 40 nouns were selected from the Colorado word norms for inclusion in the study (Toglia & Battig, 1978). Half were concrete nouns (e.g., house, wheat, pencil) that had been rated as easy to image visually. The other half were abstract nouns and were difficult to image (e.g., freedom, moment, duty). Other properties of the nouns, such as familiarity, pleasantness, and length were approximately equal in the two kinds of materials. The concrete nouns were randomly divided into two sets of 10 and one was assigned to the baseline block and the other to the dual task block. The same procedure was followed for the abstract nouns. The 10 nouns were listed on a page with space provided for each definition.

The instructions for the definition task followed those given by Sadowski et al. (1997). Participants were asked to write a "dictionary-style definition for one usage of each word." They were encouraged to "write a clear definition of each word you try" and to not worry "if you fail to define all ten words." Finally, they were told to "write clearly at a normal rate and do not be excessively concerned with the vocabulary, grammatical correctness, spelling, or editing of your definitions." The latter instruction was designed to place emphasis on sentence generation itself as opposed to the monitoring of production. The definitions were scored on a three-point scale. A score of 0 was assigned if no definition was given for a term in the 10 min. allowed. A score of 1 was given if a sketchy, poorly detailed definition was provided. This rating was used when only a single assertion was made in defining the noun. A score of 2 was given for a complete, well-detailed definition that included two or more assertions. A total score was calculated across all 10 nouns with a maximum score of 20. Two judges rated each definition and the inter-judge reliabilities were $r = .89$ for baseline sentences and $r = .90$ for experimental sentences. The ratings averaged across the two judges were used in the analyses described next.

7.3. Results

7.3.1. Definitions

Replicating Sadowski et al. (1997), an analysis of variance (ANOVA) conducted on the definition scores produced a reliable main effect of materials, F (1, 56) = 41.25, MSE = 5.64, $p < .001$. The concrete nouns ($M = 18.9$) received higher scores overall than the abstract nouns ($M = 16.1$). No other effects were reliable. The kind of working memory task performed did not affect performance on the primary composition task. This indicates that participants gave priority to the composition task.

In fact, the scores were just as high in the dual task condition as in the baseline or control condition (see Table 1). The secondary task of detecting either a new phonological segment or a new shape did not disrupt sentence production processes. This result further strengthens the case that sentence production proceeded normally as would be expected if writing took priority.

Table 1: Means and standard errors of definition scores.

	Materials	
Task	**Concrete**	**Abstract**
Baseline control		
Verbal	18.8	16.2
	(.35)	(.59)
Visual	18.7	16.0
	(.41)	(.62)
Dual task		
Verbal	19.1	16.6
	(.87)	(.60)
Visual	19.0	15.8
	(.26)	(.67)

Note: Standard errors are given in parentheses ($n = 15$).

7.3.2. Sentence Length

The definitions of concrete nouns were also reliably longer than those of abstract nouns, $F\,(1, 56) = 11.55$, MSE $= 20.71$, $p < .01$, as shown in Table 2. This outcome is consistent with the finding that concrete nouns elicited richer, more detailed definitions than did abstract nouns. There were no other reliable sources of variance.

A reduction in sentence length was not observed with the modest loads placed on visual and verbal working memory here. Consistent with previous findings (Kellogg, 2004), sentence length appears to be truncated only when a heavy load is placed on verbal working memory (e.g., retaining six digits). The visual and verbal WM tasks were non-reactive in that production processes did not appear to be altered judging from sentence length.

7.3.3. Secondary Task Accuracy

The next question concerns the difficulty of the two secondary tasks. There were no reliable differences in the accuracy of detecting targets between the verbal and visual tasks when they were performed in isolation in the control condition (Table 3). This is an important result because it demonstrates that the two tasks were of comparable difficulty. It supports our assumption that the visual and verbal tasks made equal demands on executive attention when performed without concurrent writing.

Adding the secondary task to writing reliably interfered with the accuracy of responding to the secondary task. Overall, the percentage of correct responses dropped from 87.9% during baseline to 83.1% during dual task conditions. The reduction in accuracy was about the same for either the verbal or visual task and for both types of nouns, indicating that the writing and secondary tasks competed for one or more resources of working memory. It is likely that the executive functions required to carry out the two tasks at once were overloaded.

Table 2: Means and standard errors of words per sentence.

	Materials	
Task	**Concrete**	**Abstract**
Baseline control		
Verbal	11.1	9.6
	(.64)	(1.27)
Visual	12.2	16.0
	(.89)	(.65)
Dual task		
Verbal	11.5	9.3
	(.78)	(1.17)
Visual	13.0	8.7
	(.26)	(.64)

Note: Standard errors are given in parentheses ($n = 15$).

Table 3: Mean percentages of correct responses to targets and standard errors.

Task	Materials	
	Concrete	**Abstract**
Baseline control		
Verbal	88.6	83.4
	(3.0)	(4.5)
Visual	89.8	89.9
	(2.2)	(2.4)
Dual task		
Verbal	84.4	77.9
	(2.6)	(5.1)
Visual	87.1	82.9
	(2.1)	(2.5)

Note: Standard errors are given in parentheses ($n = 15$).

Clearly, the effect was not limited to verbal or visual working memory but affected both equally as would be expected if the shared resource were the central executive.

The main effect of measurement condition was the only reliable effect, F (1, 56) = 15.23, MSE = 48.4, $p < .001$, in the ANOVA. Thus, performance suffered a little when the working memory tasks were combined with writing definitions, but accuracy was still high with fewer than 20% missed targets. Moreover, accuracy was unaffected by the kind of working memory task performed or the kind of words defined. Participants were able to maintain accuracy but it is possible that they did so only by slowing their response times, which are presented next.

7.3.4. Secondary Task RT

The mean RT to hits in the target detection task are presented in Table 4 for the various conditions. The mean RT did not differ reliably among the four conditions during the baseline control measurements. Thus, the participants were able to perform either the control visual or control verbal task just as accurately and as rapidly. Again, this outcome is important in establishing that the two tasks are of equal difficulty when performed in isolation.

The mean RT increased reliably when tested in the dual task situation in all cases except the abstract-visual condition. The largest increase observed was in the concrete-visual condition. This pattern was supported by a reliable measurement X materials X task interaction, F (1, 56) = 9.48, $p < .01$. There was also a reliable main effect of measurement condition, F (1, 56) = 53.51, $p < .001$ and materials X measurement interaction, F (1, 56) = 4.57, $p < .05$, MSE = 17.0 for all effects. Thus, writing definitions slowed the time needed to respond to the targets in the verbal task regardless of whether low or high imagery nouns were used. The visual task, on the other hand, showed RT interference only with concrete

Table 4: Means and tandard errors for secondary task reaction time (ms).

Task	**Materials**	
	Concrete	**Abstract**
Baseline control		
Verbal	891(61)	841 (57)
Visual	790 (44)	909 (65)
Dual task		
Verbal	1033 (66)	1028 (75)
Visual	1094 (75)	967 (62)

Note: Standard errors are given in parentheses.

nouns that presumably evoked images in planning the content of the definition. The selective increase for concrete nouns only in the visual task suggests RT interference effects are not entirely accountable in terms of competition for executive resources of working memory. The lack of interference with the visual task for abstract nouns is problematic for an account based on sharing attention to cope with the dual task demands.

7.4. Discussion

It was hypothesized that verbal working memory supports necessary processes in written sentence production, whereas visual working memory supports optional processes associated with the planning of image-based semantic content. Here, writing a definition to either a concrete or an abstract noun slowed the responses made to a concurrent verbal working memory task. This outcome is consistent with the notion that linguistic encoding is not modular and required the use of verbal working memory.

As expected, the visual working memory task was slowed only by concrete nouns. The planning of conceptual content prior to grammatical and phonological encoding was assumed to be sensitive to whether images as well as propositions were retrieved and maintained in working memory. Sadowski et al. (1997) concluded that concrete words activate both imaginal and propositional representations in planning the content of definitions. Dual coding supports superior definitions. The present study replicated their results and further showed that image-based conceptual content interferes with a concurrent visual working memory task.

Past studies have shown that heavy loads on verbal working memory disrupt sentence production (Fayol et al., 1994; Kellogg, 2004; Power, 1985; Ransdell et al., 2002). It could be that part of these effects were because the central executive was also heavily loaded. Here we observed an interaction of task and materials, despite that both tasks made the same demands on the central executive and were equally difficult during baseline conditions. The present findings strengthen the case that verbal working memory per se is involved in translating an idea into a sentence.

One might object that the visual task allowed verbal encoding of the shapes because triangle and circle were easily named. If that were the case, then interference should have been found for both concrete and abstract nouns in the visual as well as the verbal task. Even so, in future work, it would be useful to replicate the findings using unfamiliar objects that cannot be readily named and discriminated on the basis of verbal labels.

The selective disruption caused by concrete nouns on the visual task should be replicated and contrasted with a spatial task in which participants respond to location rather than shape. We anticipate that neither concrete nor abstract nouns will slow responding to spatial location, although other kinds of writing tasks may well show such interference (e.g., defining the location of a landmark within a city). The demands of sentence production on working memory are possibly highly task specific. In line with this speculation, Passerault and Dinet (2000) reported that writing fluency is disrupted by a visual concurrent task when composing a descriptive text but not when composing an argumentative text.

7.4.1. Conclusion

Both, the sentence length effect caused by a heavy, six-digit load on verbal working memory and the present findings, indicate that verbal working memory is necessary for unimpeded sentence generation. By contrast, visual working memory appears to play a more selective role. Further, the visual working memory task investigated here revealed RT interference with writing the definitions only for concrete nouns that are readily imaged. Visual working memory, then, appears to be involved in sentence generation at the planning stage, when conceptual representations activate images as well as abstract prepositions.

The design of the experiment presented here offers one way to separate planning and translating ideas into sentences. However, the linguistic encoding of ideas involves multiple stages. It is unclear whether the interference observed on the verbal working memory task arose from grammatical encoding, phonological encoding, orthographic encoding, or some combination of the three. Moreover, these different kinds of linguistic encoding may be interactive rather than cascaded stages of processing (Dell, Chang, & Griffin, 2001). From a connectionist perspective, it makes little sense to ask whether the interference observed in the present experiments is isolated to one or more of these levels of encoding. Rather, it is likely that either all three levels of representation depend on the computational resources of verbal working memory or none do. The present findings speak against the modularity hypothesis of automatic linguistic encoding, but further research is needed to address specifically how written sentence generation depends on verbal working memory.

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