MAINTENANCE IN VISUO-SPATIAL WORKING MEMORY

Debora I. BURIN¹⁾, Natalia IRRAZABAL¹⁾

¹⁾*Universidad de Buenos Aires — CONICET, Argentina*

and

J. Gerry QUINN²⁾

²⁾*University of St Andrews, Scotland, UK*

Two proposed factors affecting visual working memory maintenance were explored. By means of the dynamic visual noise technique (DVN, Quinn & McConnell, 1996), perceptual structural complexity, and dynamic movement of irrelevant visual information, have been shown to affect memory for subject-generated images, but not for visual inputs. Three experiments manipulated the level of perceptual complexity (standard DVN vs. dynamic figures, and dynamic vs. static characteristics) of an interfering display, while performing a visual recognition short-term memory task employing novel polygons. Results replicated the lack of standard DVN effect on memory for visual inputs, but showed that an irrelevant visual figure, more structured than standard DVN, decreased performance. Polygon recognition was affected by a static irrelevant visual figure, but was significantly lower when it was dynamic. Interference based on perceptual factors, and spatial displacements of incoming inputs, are discussed within the context of visual working memory mechanisms and architecture.

Key words: visual working memory, interference, similarity, spatial attention

Evolving from early views about short-term memory, *working memory* refers to a set of temporary active contents and processes “involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition” (Miyake & Shah, 1999, p. 450). The multicomponent working memory model developed by Baddeley and colleagues (Baddeley, 1986, 1996; Baddeley & Logie, 1999) distinguishes amodal central executive resources from two modality specific temporary retention systems, one verbally based (the phonological loop) and another that deals with visuo-spatial material (the visuo-spatial sketch-pad). A proposed architecture for this latter component (Baddeley & Logie, 1999; Logie, 1995) has suggested that visual and spatial processes act in concert in a functional architecture similar to that of the phonological loop. A passive visual store holds visuo-spatial information, such as form, edge, or

This research was supported by the Consejo Nacional de Investigaciones Científicas y Técnicas (Res. CS N° 877/02, and Res. D N° 0205) and by the Secretaría de Ciencia y Técnica, Universidad de Buenos Aires (UBACYT P403). We thank Laura Davila and Rodolfo Halicki for programming the experimental tasks.

Correspondence concerning this article should be addressed to D. I. Burin, Instituto de Investigaciones, Facultad de Psicología — UBA, Independencia 3065 3° of. 8, (1225) Ciudad de Buenos Aires, Argentina (e-mail: dburin@psi.uba.ar).

colour, in a perceptual-like image, subject to decay unless “refreshed” by an active spatial mechanism, involved also with movement sequences and motor planning. However, this model has been the subject of many theoretical and empirical controversies. One of them, the objective of this article, concerns visual working memory’s maintenance mechanisms.

Empirical techniques including the effects of visual similarity have suggested that visual structure is maintained in the visuo-spatial sketchpad (Hue & Ericsson, 1988; Logie, Della Sala, Wynn & Baddeley, 2000). The use of irrelevant pictures has suggested that perceived inputs have direct and obligatory access to the system, causing detrimental effects on short-term recall and recognition for visuo-spatial material, analogous to the irrelevant speech effect on the phonological loop (Logie, 1986; Logie & Marchetti, 1991; Toms, Morris, & Foley, 1994). Quinn and McConnell explored the effects of passive visual interference with the *dynamic visual noise (DVN)* task, consisting of a matrix of dots turning black and white randomly, similar to television static, which the subject had to watch but otherwise ignore (McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996; 1999). This interference caused lower performance in remembering words learned under visual imagery instructions (peg-word mnemonic) but did not affect retention of words coded using rote rehearsal (Quinn & McConnell, 1996). The detrimental effect of DVN on the retention of material learned under visual imagery instructions has been replicated in multiple experiments (Andrade, Kemps, Werniers, May, & Szmalec, 2002; Baddeley & Andrade, 2000; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1999).

Further explorations of visual working memory’s maintenance mechanisms with the DVN technique point to at least two characteristics required for the irrelevant visual material to interfere: (1) dynamic movement, and (2) perceptual complexity of the visual material. Regarding the first one, Quinn and McConnell (1999) showed that a single on / off static dot did not cause interference, but did so when the dot changed its location, suggesting that the interference exerted its effects through a spatially based active rehearsal mechanism, which is indeed the mechanism originally suggested by Logie (1995) in his original model. This mechanism has further been linked to spatial attention in sequential spatial working memory (Salway & Logie, 1995; Smyth & Scholey, 1994), but the role of spatial attention in visual objects’ working memory maintenance is controversial (see discussion in Awh, Vogel & Oh, 2006).

As for the second factor, perceptual complexity, McConnell and Quinn (2004) manipulated the number of dots, the density of the spatial field (spatial grouping), and the size of the field, all of them showing incremental interference effects. Thus, the more complex a perceptual irrelevant input is, more interfering effects seemed to follow. Number of dots, spatial grouping, and size, were considered primary contributors to perceptual complexity, as compared with higher-level manipulations of complexity such as symmetry or repetition, a distinction based on the level of perceptual analysis required (Ichikawa, 1985). Although varying greatly in their assumptions and dynamics, theories of perception distinguish a lower level of analysis of visual features (such as lines, angles, orientation of lines, color, etc), and further stages of processing where a structural description or a general, more abstract shape is constructed or accessed (Ullman, 1995).

Visual working memory is sensitive to not only to the number of visual features, but especially to the surface complexity of visual objects (Alvarez & Cavanagh, 2004; Eng, Chen, & Jiang, 2005).

One possible explanation for these effects is in terms of similarity (features and structural properties) shared by the target and irrelevant material (Logie et al., 2000); although the visual similarity between a random dots field and a mental image of a known object remains questionable. Given that interference effects were found when the image was generated, an alternative position espoused by several authors (Andrade et al., 2002; Pearson, Logie, & Gilhooly, 1999; Quinn & McConnell, 2006) suggests that low level perceptual manipulations interfere in conscious imagery, but not in visual maintenance of complex stimuli.

This latter view was proposed after finding that the effects of DVN could not be replicated in conditions where visual working memory contained products of visual input instead of images generated from verbal descriptions. In a series of experiments performed by Andrade et al. (2002), DVN neither affected the short-term recognition, nor the recency effect of visually presented matrix patterns, modelled after Phillips and Christie (1977) (Exp. 4), nor the short-term recognition of Chinese characters (Exp. 5). In addition, Zimmer, Speiser, and Seidler (2003) did not find effects of DVN on a pattern memory (object and abstract drawings' location) task. This lack of DVN effect on visual short-term memory for visual inputs has led Andrade et al. (2002) to suggest a separation between an active visual buffer that manipulates conscious visual images, from a passive visual store that holds temporary visual representations. Pearson et al. (1999) proposed a similar argument, after finding that DVN did not affect performance on mental synthesis tasks. In a related view, Quinn and McConnell (2006) argued for a separation between a medium for conscious images and a component holding a structural description of the visual items.

Therefore, the objective of this paper was to test whether these two sources of interference (perceptual aspects and dynamic movement of the irrelevant information) explored with the DVN technique in imagery tasks, could additionally apply to visual memory for perceived inputs. In a set of experiments, we have tested the effects of irrelevant visual material, shown in the retention interval of a short-term recognition task for visually presented random polygons. Experiment 1 replicated the lack of effect of the standard DVN interference. Experiment 2 compared standard DVN with another dynamic irrelevant visual noise, but perceptually more complex (a geometric figure) than standard noise, showing that the latter caused lower memory performance. Experiment 3 found that retention of the random polygon was more strongly affected when the irrelevant visual noise was dynamic than when it was static, supporting the idea that spatial displacements of the irrelevant information are an additional source of interference. These results are discussed in terms of possible mechanisms and architecture of visual working memory.

EXPERIMENT 1

This experiment tested whether standard DVN affected the retention of a visually presented random polygon. The memory task required recognition of a random polygon between two distractors. Given the tendency to verbally recode visual material, foils were created by adding or subtracting a detail (side, angle, portion of surface), so that even though subjects could label the polygon, that strategy was not effective to discriminate target from distractors. We also tested the visual nature of the memory task, with an articulatory suppression interference. If the task required specialized visual working memory resources, there should be no significant performance decrements with a verbal secondary task.

Method

Subjects:

Twenty four subjects (5 men, 19 women), first year students at the Facultad de Psicología, Universidad de Buenos Aires, volunteered to participate in exchange for course credit. Their mean age was 21 years, *s.d.* = 3.6.

Materials:

— *Visual working memory task:* This task required the short-term recognition of a visually presented polygon, among two distractors. Polygons were created by randomly connecting points in a 255 pixels wide by 199 pixels high matrix, or in another one, square matrix, covering 255 pixels wide and high. Figures were then filled in black, and redesigned according to pre-testing: those presenting more than eight salient points were eliminated or modified, because pilot tests showed that figures with too many points led to a non-visual point-counting strategy, and figures with less than five points were also excluded, because they were too easy to recognize among distractors. Only figures with convex angles were included. Distractors were created modifying one detail (side, point, or portion of surface) of the target figure. No figure was repeated in testing. Figure 1 shows three examples of a target polygon and its distractors; examples of target figures are also shown in the upper part of Figure 2.

— *Dynamic Visual Noise:* Visual noise fields were derived from Quinn & McConnell (1996, 1999). A squared area (480×480 pixels) covering the center of the screen was divided in random black and white dots (6×6 pixels). Half of the dots changed randomly from black to white and viceversa at a 1 second rate.

All tasks were programmed in Visual Basic and run on an IBM-compatible PC equipped with a Pentium III processor and a 15 inches VGA monitor with 800×600 screen resolution.

Procedure:

Working memory tasks were completed in one session. Each session started with instructions for the memory task without interference. After 4 practice examples (or the number needed to achieve 2 correct trials, if this criterion was not met in the first 4 examples) instructions for the corresponding experimental condition were given. Each experimental block started with 4 practice examples (or until 2 correct trials were achieved), and consisted of 30 experimental trials per condition.

Each trial began with an alert signal (a “+”) lasting 500 msec., followed by the visual stimulus presented centrally for 1 second. After a 7 seconds retention interval (blank or filled with an interference task), the target stimulus and distractors appeared for 8 seconds. The target stimulus appeared one-third of the times in each of three horizontal positions. Subjects answered which was the target figure by pressing “1”, “2” or “3” on the numerical keyboard. After the subjects' response, a cross was shown centrally on the screen for 500 msec., signalling the beginning of the following trial. Figure 1 shows a sample trial.

Subjects completed 30 experimental trials in each condition: No Interference, Verbal Interference, Dynamic Visual Noise Interference:

— *No Interference (NI):* no secondary task in the retention interval.

— *Verbal Interference (Vbl):* once the figure disappeared the participants started saying “bla bla bla”.

Fig. 1. Examples of trials for visual working memory in each condition (No Interference, Verbal Interference, Dynamic Visual Noise Interference). Note: Actual size and form of stimuli can be distorted.

If they did not do so, the experimenter (seated behind the participant and out of view) prompted them by saying “bla ...”.

— *Dynamic Visual Noise Interference (DVN)*: after the figure, the screen presented the black-and-white dots field during the retention interval. Half of the dots changed randomly from black to white and viceversa each second. The subject was instructed to “just look” at the screen.

Type of interference (NI, VbI, DVN) was manipulated within subjects. Order of conditions was counterbalanced, and assigned at random.

Results and Discussion

One univariate outlier (± 2.5 *s.d.*) was found in correct responses’ distributions for the No Interference condition, and was excluded from the final sample ($n = 23$). Table 1 (left) shows the means and standard deviations for the proportion of correct responses in each of the experimental conditions.

The effect of the Type of interference (NI, VbI, DVN) was examined with a repeated measures ANOVA, which was not significant ($F(2, 44) = 1.98$, $MSE = 4.24$, $p > 0.05$, $\text{Eta}^2 = 0.08$). Table 1 shows that mean percent of correct responses was of similar magnitude along the three interference conditions, around 0.70, and paired comparisons (t tests for related samples) revealed no significant differences between them (NI-VbI: $t_{22} = 1.70$, $p > 0.05$; NI-DVN: $t_{22} = 1.66$, $p > 0.05$; VbI-DVN: $t_{22} = 0.15$, $p > 0.05$).

Table 1. Mean Proportion Correct, and *S.D.*, of Visual Memory Performance, for each Experimental Condition in each Experiment.

Condition	<i>Experiment 1</i>		<i>Experiment 2</i>		<i>Experiment 3</i>	
	<i>Mean</i>	<i>S.D.</i>	<i>Mean</i>	<i>S.D.</i>	<i>Mean</i>	<i>S.D.</i>
NI	.72	.08	.70	.09	.71	.10
VbI	.68	.06				
DVN	.68	.08	.72	.11		
DVF			.53	.09	.57	.11
SVF					.62	.10

Note: NI.: No Interference; VbI: Verbal Interference; DVN: Dynamic Visual Noise; DVF: Dynamic Visual Figure; SVF: Static Visual Figure.

A non-significant effect can be a result of lack of statistical power, but given the very small magnitude of the effect size ($\eta^2 = 0.08$), and previous literature, these results can be considered as expected. The verbal interference's lack of significant effect was predicted, and confirms the task did not involve verbal recoding. The fact that standard DVN did not have a significant effect on short-term memory for visual inputs replicates Andrade et al. (2002) and Zimmer et al. (2003). Nevertheless, this interference was tested again in Experiment 2, along with another visual irrelevant interference, differing from standard DVN in the degree of perceptual complexity.

EXPERIMENT 2

This experiment compared the effects of two types of irrelevant dynamic interference, presented in the retention interval of a short-term recognition memory task for visually presented material. Standard DVN was compared with another dynamic irrelevant, but perceptually more complex, interference, namely, a geometric figure moving along the screen (the Dynamic Visual Figure condition). Geometric figures have not only perceptual features, but also visual structural properties, so should result in larger interference effects than those obtained by dynamic visual noise comprised of random dots.

Method

Subjects:

Thirty subjects (29 women, 1 man), first year students at the Facultad de Psicología, Universidad de Buenos Aires, volunteered to participate in exchange for performance feedback and course credit. Their mean age was 19.7 years, *s.d.* = 1.2.

Material:

The same computer tasks and equipment as in Exp. 1 were used, with the addition of a new interference

Fig. 2. Examples of figures for the visual working memory task. Above: Examples of target items. Below: Examples of figures for visual interference (Exps. 2 & 3). Note: Stimuli are shown smaller than their original size.

task, the *Dynamic Visual Figure*, which consisted of a black geometric figure (a rectangle, two triangles, or a parallelogram), slightly smaller than target figures (130×106 pixels, 163×94 pixels, and 123×116 pixels, respectively), crossing the screen at a change rate of four linear movements per second. Examples of target polygons and geometric figures used for interference can be seen in Figure 2.

Procedure:

The general structure of the experimental session was similar to Exp. 1, except for the Dynamic Visual Figure interference condition instead of the verbal interference condition. Also, the presentation time of the to-be-remembered polygon was extended (2 seconds instead of 1), as was the time to respond (10 seconds, compared to 8 seconds in Exp. 1).

Subjects completed 30 experimental trials in each condition: No Interference, Dynamic Visual Noise, Dynamic Visual Figure:

No Interference (NI): no secondary task in the retention interval.

Dynamic Visual Noise (DVN): same as Experiment 1.

Dynamic Visual Figure (DVF): after the to-be-remembered figure, a randomly selected black polygon (a rectangle, a parallelogram, or a triangle), crossed the screen (upward, downward, horizontal, or in diagonal), at a change rate of four linear movements per second. The subject was instructed to “just watch it”.

Type of interference (No Interference, Dynamic Visual Noise, Dynamic Visual Figure) was manipulated within subjects. Order of conditions was counterbalanced, and assigned at random.

Results and Discussion

No univariate outlier (± 2.5 *s.d.*) was found in correct responses' distributions. Table 1 (center) shows performance in each of the experimental conditions.

The effect of the Type of interference (NI, DVN, DVF) was examined with a repeated measures ANOVA, which was significant ($F(2, 58) = 57.01$, $MSE = 5.16$, $p < 0.01$, $\eta^2 = 0.66$). Paired comparisons (*t* tests for related samples) revealed that performance on the Dynamic Visual Figure was significantly worse than in both other conditions (NI-DVF: $t_{29} = 9.35$, $p < 0.01$; DVN-DVF: $t_{29} = 8.18$, $p < 0.01$). There was no significant difference between the No Interference condition and the standard Dynamic Visual Noise condition ($t_{29} = 1.20$, $p > 0.05$).

In the first place, the lack of effect of standard DVN on memory for a visual input was again replicated, thus reinforcing the idea that this absence of effect is not caused by

statistical power. Nevertheless, the Dynamic Visual Figure led to a significant decrement. As different from DVN, the irrelevant figures shared some features with the target polygons, although they belonged to a different class of geometrical figures and were of a different size. An additional difference between DVN and irrelevant geometric figures is that the latter have structural properties, so that the source of interference could be placed not only at the lower perceptual level but in similarity at the level of structural description.

However, in order to maintain a dynamic aspect to the structured figure, a significant confound may have been introduced. In their design of DVN, Quinn and McConnell (1996) argued that the nature of the dynamic aspect of DVN did not lead to attention being directed to any particular place on the display at any particular time. This has been an important aspect of DVN since following a movement in a particular direction engages spatial attention (Quinn, 1994) which, of itself, could explain the increase in interference effects. Experiment 3 compared the effects of the Dynamic Visual Figure interference, with a Static Visual Figure, similar to the former, except that the figure did not move. Thus, Experiment 3 explores the effects of perceptual factors excluding the spatial movement factor.

EXPERIMENT 3

This experiment compared the effects of two types of irrelevant visual noise, presented in the retention interval of the same polygon recognition task as previous experiments. One of the interferences consisted of the Dynamic Visual Figure task employed in Exp. 2. The other interference was a static geometric figure (similar to the set of figures used for the former condition), shown centrally during the retention interval (the Static Visual Figure condition). This comparison allows a separation between two candidate factors which may have cause the interference: perceptual complexity, and spatial movement. Does the Dynamic Visual Figure exert an effect on visual memory because of its dynamic properties? Or are perceptual properties of the irrelevant information the relevant factor? The first alternative predicts that only the Dynamic Visual Figure will have an effect on memory, whereas the second predicts also Static Visual Figure effects.

Method

Subjects:

Thirty subjects (28 women, 2 men), first year students at the Facultad de Psicología, Universidad de Buenos Aires, volunteered to participate in exchange for course credit. Their mean age was 20.2 years old, *s.d.* = 1.9.

Materials:

This experiment employed the same visual memory task (short-term recognition of a random polygon), implemented in the same computer equipment. A new interference task was created, the *Static Visual Figure*, which consisted of a black polygon, presented centrally, in the same location as the to-be-remembered figure. The polygon was randomly selected from a set comprising a rectangle, two parallelograms, and three triangles, slightly smaller than the target figure.

Procedure:

Each trial had the same structure as in the previous experiment (Exp. 2).

Subjects completed 30 experimental trials in each condition: No Interference, Dynamic Visual Figure Interference, Static Visual Figure Interference:

No Interference (NI): no secondary task in the retention interval.

Dynamic Visual Figure (DVF): same as Experiment 2.

Static Visual Figure Interference (SVF): after the to-be-remembered figure, the screen presented a randomly selected black figure (a rectangle, a parallelogram, or a triangle), centrally, in the same location where the target figure was presented. The subject was instructed to “just look” at the figure.

Type of interference (NI, DVF, SVF) was manipulated within subjects. Order of conditions was counterbalanced, and assigned at random.

Results and Discussion

Distribution of correct responses showed no outliers (± 2.5 s.d.). Table 1 (right) shows performance in each of the experimental conditions.

The effect of the Type of interference (NI, DVF, SVF) was significant ($F(2, 58) = 15.96$, $MSE = 8.02$, $p < 0.01$, $\eta^2 = 0.36$). Paired comparisons for related samples revealed significant differences between both interferences and the No Interference condition (NI-DVF: $t_{29} = 5.43$, $p < 0.01$; NI-SVF: $t_{29} = 3.47$, $p < 0.01$). The difference between SVF and DVF was also significant ($t_{29} = 2.08$, $p < 0.05$).

Both interferences had a significant effect, which reinforces the idea that irrelevant visual inputs can exert detrimental effects for visual working memory. The comparison between the Dynamic and the Static visual interferences suggests that dynamic characteristics of the display combine additively with its perceptual features. Thus, maintenance would be not only a function of a “spatial rehearsal” mechanism, but also a visually based mechanism.

GENERAL DISCUSSION

This paper has presented three experiments focused on the problem of interference in visual working memory for visually presented polygons. In keeping with Andrade et al. (2002) and Zimmer et al. (2003), experiment 1 has shown that DVN, comprised of a field of random dots, presented during the retention interval, does not disrupt memory for polygons. However, experiments 2 and 3 showed that more complex irrelevant figures decrease recognition performance. As verbal interference was also ineffective in causing disruption, the effect cannot be attributed to verbal coding of stimuli, or to a general resource reduction.

The results of experiment 2, and especially experiment 3, supported the idea that irrelevant incoming visual information will decrease visual working memory. Experiment 3 showed that perceptual aspects and spatial changes of the irrelevant information (whether the interference was static or moving along the screen) combined additively. The effects were obtained with visually presented material, unlike previous research employing imagery tasks. Also, the irrelevant visual interference was presented during a retention interval, that is, not concurrent with image coding. These characteristics contrast

with previous research with DVN, that found effects only during image coding, but not when retaining a visually presented stimulus (Andrade et al., 2002; Zimmer et al., 2003). Our results show that perceptual similarity is a factor affecting visual working memory beyond the coding stage (Hue & Ericsson, 1988; Logie et al., 2000). In our case, complex polygons were susceptible to interference by geometric figures, which are more similar than DVN in terms of features (sides, angles), but also in their perceptual structural description (surface, symmetry, relations between parts). Apart from the stage where similarity arises (coding vs. retention interval), our material also differs from intra-list manipulations, which employed letters (Logie et al., 2000), and Chinese characters shown to occidental subjects (Hue & Ericsson, 1988). An interesting question, and pertinent to the question of visual working memory architecture, would be whether errors induced by intra-list similarity and errors produced by similarity of irrelevant items in a retention interval, arise from the same source.

Within Logie's (1995) theory, the cache is the only short term visual storage mechanism whose content may be refreshed by regeneration, a process driven by the "inner scribe", a spatially based mechanism not further clarified. Experiment 3 found that spatial changes of the irrelevant information were an additional factor of interference, apart from visual features. Thus, the interfering property of spatial displacement of an irrelevant incoming visual information would point to spatially based rehearsal as suggested by the original model. A proposed mechanism for this effect is that such movements induce movements of visuo-spatial attention, which would be necessary for image maintenance (Quinn & McConnell, 1999). Indeed, as discussed in Experiment 2, the rationale for creating DVN as random dots was that following a trajectory of a figure would induce spatial attention movements (Quinn & McConnell, 1996). Unlike DVN, which did not cause interference, the Dynamic Visual Figure could be engaging spatial attention. Several experiments have shown the link between spatial attention and spatial, or sequential, working memory maintenance (Salway & Logie, 1995; Smyth & Scholey, 1994). Nevertheless, in the visual attention literature, visual search performed in the retention interval of a spatial working memory task produced decrements in both search and memory tasks (Woodman & Luck, 2004), but not when combined with a visual memory task (color or form change detection) (Woodman, Vogel, & Luck, 2001). Spatial attention decreased spatial, but not visual, working memory. Thus, whether the dynamic aspect of the interference exerts its effects through visual attention is a matter of further research.

However, a spatially based rehearsal mechanism alone cannot account for the visual similarity effects, which were found to be independent of spatial changes of the irrelevant information (Exp. 3). Interference by the static figure, as compared with DVN, could be explained together with effects of visual similarity between visual inputs previously found in the literature. It could be argued that the effect is a product of similarity at the low-level perceived features. On the other hand, placing the mechanism at that level would have difficulty accounting for DVN effects in imagery. As stated in the Introduction, inspired by these latter effects, and by Kosslyn's model (1991), several authors have suggested an architecture for visual working memory that separates an active visual buffer that

manipulates conscious visual images, from a passive visual store that holds temporary visual representations (Pearson, 2001; Quinn & McConnell, 2006). The former would be the locus of conscious visual images, retaining perceptual aspects, and would also be directly accessible to perceptual inputs from the environment; while the latter would temporarily store more abstract shape and object patterns, connected with both the visual buffer and long term memory. Within this architecture for visual working memory and imagery, DVN causes interference with a perceptual representation in a visual buffer, thus disturbing conscious imagery processes. But when the image has been perceived, and its structural properties stored, only more complex patterns, with comparable or similar structural descriptions, would have detrimental effects. From this point of view, the static figure would impair memory for polygons because of their similarity at the more abstract, structural description level.

In sum, the experiments have shown that perceptual factors and dynamic changes of an incoming visual irrelevant information are both sources of interference for visual working memory maintenance. Current models of visual working memory can accommodate these results, but stressing different sources for these interferences. The relationship between spatial displacement and visual attention remains to be determined; as well as whether the perceptual factor that matters is mere complexity, or similarity at the features, or structural description level.

REFERENCES

- Alvarez, G. A., & Cavanagh, P. 2004. The capacity of visual short term memory is set both by visual information load and by number of objects. *Psychological Science*, **15**, 106–111.
- Awh, E., Vogel, E. K., & Oh, S. H. 2006. Interactions between attention and working memory. *Neuroscience*, **139**, 201–208.
- Andrade, J., Kemps, E., Werniers, Y., May, J., & Szmalec, A. 2002. Insensitivity of visual short-term memory to irrelevant visual information. *Quarterly Journal of Experimental Psychology*, **55A**, 753–774.
- Baddeley, A. D. 1986. *Working Memory*. Oxford: Oxford University Press.
- Baddeley, A. D. 1996. The fractionation of working memory. *Proceedings of the National Academy of Sciences*, **93**, 13468–13472.
- Baddeley, A. D., & Andrade, J. 2000. Working memory and the vividness of imagery. *Journal of Experimental Psychology: General*, **129**, 126–145.
- Baddeley, A. D., & Logie, R. H. 1999. Working memory: the multiple-component model. In A. Miyake, & P. Shah (Eds.), *Models of working memory. Mechanisms of active maintenance executive control* (pp. 28–61). New York, NY: Cambridge University Press.
- Eng, H. Y., Chen, D., & Jiang, Y. 2005. Visual working memory for simple and complex visual stimuli. *Psychonomic Bulletin and Review*, **12**, 1127–1133.
- Hue, C. W., & Ericsson, J. R. 1988. Short-term memory for Chinese characters and radicals. *Memory and Cognition*, **16**, 196–205.
- Ichikawa, S. 1985. Quantitative and structural factors in the judgement of pattern complexity. *Perception and Psychophysics*, **38**, 101–109.
- Kosslyn, S. M. 1991. A cognitive neuroscience of visual cognition: Further developments. In R. H. Logie & M. Denis (Eds.), *Mental images in human cognition* (pp. 351–381). Amsterdam: Elsevier Science Publishers.
- Logie, R. H. 1986. Visuo-spatial processing in working memory. *Quarterly Journal of Experimental Psychology*, **38A**, 229–247.

- Logie, R. H. 1995. *Visuo-spatial working memory*. Hove, UK: Lawrence Erlbaum Associates.
- Logie, R. H., & Marchetti, C. 1991. Visuo-spatial working memory: Visual, spatial or central executive? In R. H. Logie, & M. Denis (Eds.), *Mental Images in Human Cognition* (pp. 105–115). Amsterdam: Elsevier Science Publishers.
- Logie, R. H., Della Sala, S., Wynn, V., & Baddeley, A. D. 2000. Visual similarity effects in immediate verbal serial recall. *Quarterly Journal of Experimental Psychology*, **53A**, 626–646.
- McConnell, J., & Quinn, J. G. 2000. Interference in visual working memory. *Quarterly Journal of Experimental Psychology*, **53A**, 53–67.
- McConnell, J., & Quinn, J. G. 2004. Complexity factors in visuo-spatial working memory. *Memory*, **12**, 338–350.
- Miyake, A., & Shah, P. 1999. Toward unified theories of working memory: Emerging general consensus, unresolved theoretical issues, and future research directions. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 442–481). Cambridge, UK: Cambridge University Press.
- Pearson, D. G. 2001. Imagery and the visuo-spatial sketchpad. In J. Andrade (Ed.), *Working Memory in Perspective*. Hove: The Psychology Press.
- Pearson, D. G., Logie, R. H., & Gilhooly, K. J. 1999. Verbal representations and spatial manipulation during mental synthesis. *European Journal of Cognitive Psychology*, **11**, 295–314.
- Phillips, W. A., & Christie, D. F. 1977. Components of visual working memory. *Quarterly Journal of Experimental Psychology*, **29**, 117–133.
- Quinn, J. G. 1994. Towards a clarification of spatial processing. *Quarterly Journal of Experimental Psychology*, **47A**, 65–480.
- Quinn, J. G., & McConnell, J. 1996. Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology*, **49A**, 200–215.
- Quinn, J. G., & McConnell, J. 1999. Manipulation of interference in the passive visual store. *European Journal of Cognitive Psychology*, **11**, 373–389.
- Quinn, J. G., & McConnell, J. 2006. The interval for interference in conscious visual imagery. *Memory*, **14**, 241–252.
- Salway, A. F. S., & Logie, R. H. 1995. Visuospatial working memory, movement control and executive demands. *British Journal of Psychology*, **86**, 253–269.
- Smyth, M. M., & Scholey, K. A. 1994. Interference in immediate spatial memory. *Memory & Cognition*, **22**, 1–13.
- Toms, M., Morris, N., & Foley, P. 1994. Characteristics of visual interference with visuospatial working memory. *British Journal of Psychology*, **85**, 131–144.
- Ullman, S. 1995. The visual analysis of shape and form. In M. S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 339–350). Cambridge, MA: The MIT Press.
- Woodman, G. F., & Luck, S. J. 2004. Visual search is slowed when visuospatial working memory is occupied. *Psychonomic Bulletin & Review*, **11**, 269–274.
- Woodman, G. F., Vogel, E. K., & Luck, S. J. 2001. Visual search remains efficient when visual working memory is full. *Psychological Science*, **12**, 219–224.
- Zimmer, H. D., Speiser, H. R., & Seidler, B. 2003. Spatio-temporal working memory and short-term object location tasks use different memory mechanisms. *Acta Psychologica*, **114**, 41–65.

(Manuscript received October 31, 2006; Revision accepted April 24, 2007)