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Selective interference with image retention and generation: Evidence for the workspace model

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Selective interference with image retention and generation: Evidence for the workspace model

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We address three types of model of the relationship between working memory (WM) and long-term memory (LTM): (a) the gateway model, in which WM acts as a gateway between perceptual input and LTM; (b) the unitary model, in which WM is seen as the currently activated areas of LTM; and (c) the workspace model, in which perceptual input activates LTM, and WM acts as a separate workspace for processing and temporary retention of these activated traces. Predictions of these models were tested, focusing on visuospatial working memory and using dual-task methodology to combine two main tasks (visual short-term retention and image generation) with two interference tasks (irrelevant pictures and spatial tapping). The pictures selectively disrupted performance on the generation task, whereas the tapping selectively interfered with the retention task. Results are consistent with the predictions of the workspace model.

Keywords: Working memory; Visual imagery; Visual short-term memory; Mental workspace.

The field of working memory (WM) has made significant progress during the past three decades, reflected in a range of models each with different characteristics (for reviews, see Logie & D'Esposito, 2007; Miyake & Shah, 1999; Osaka, Logie, & D'Esposito, 2007). Here, we address experimentally three types of model, which differ fundamentally in their assumptions about the relationship between WM, long-term memory (LTM), and perceptual processes.

1. The *gateway model* originates from early information-processing models of memory that assume a structural distinction between LTM and short-term memory (STM) or WM and consider WM as a *gateway* between perceptual input and LTM as well as supporting mental imagery. Perceptual information accesses WM directly with subsequent transfer of selected information to LTM (e.g., Atkinson & Shiffrin, 1968; Broadbent, 1958; Waugh & Norman, 1965). This idea of WM as a gateway is still described in textbooks (e.g., Eichenbaum, 2008; Kosslyn & Rosenberg, 2004), is present in theories that link perception with imagery (e.g., Kosslyn, 2005),

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and is implicitly present in the Baddeley (2002, 2007; Baddeley & Hitch, 1974) model of working memory, described as a store for visuospatial and verbal information, accessed either from perception or from LTM. The visuospatial sketch pad (VSSP) within the Baddeley and Hitch model also is thought to support both mental imagery and visual temporary memory.

2. The *unitary model* assumes that WM and LTM reflect the operation of the same system. Support arose from the observation that STM and LTM are associated with similar memory phenomena (e.g., Crowder, 1993) and from neuroimaging data suggesting that the same brain areas are active during working-memory retention, during perception, and during retrieval from long-term episodic memory (e.g., Postle, 2007; Ruchkin, Grafman, Cameron, & Berndt, 2003). One influential version of this view was proposed by Cowan (1988, 2005), who defined WM as the activated portion of LTM coupled with limited capacity attention. WM and LTM are seen as different states of the same representations, and memory storage is assumed to take place in the same neural structures in which the information was initially processed (e.g., Cowan, 1999; Cowan, Morey, Chen, & Bunting, 2007). Representations in LTM are hypothesized to be maintained by activation in a capacity limited "focus of attention" for short-term retention and processing. The model is unitary in that it denies the existence of separate *structures*. However, it retains the idea of separate short- and long-term memory *processes* (Cowan, 2003).

3. In the *workspace model* (e.g., Logie, 1995, 2003; Logie & van der Meulen, 2008) perceptual information first accesses previously stored knowledge, and the activated long-term representations are made available to a separate WM system. WM acts as a mental workspace that holds and manipulates the activated representations. This view arose in response to several problems with the gateway and unitary models. First, visual representations held in WM are identified objects that have associated meaning drawn from previous experiences with the object or scene held in LTM (e.g., Chambers & Reisberg, 1992; Logie, 1995). They are not raw sensory images of edges and contours. In this paper we focus on visuospatial aspects of working memory. However, the same can be argued for verbal representations (e.g., Hulme, Roodenrys, Brown, & Mercer, 1995; Reisberg, Smith, Baxter, & Sonenshine, 1989; reviewed in Baddeley, 2007). Thus, contrary to the gateway view, perceptual input appears first to activate representations in LTM before accessing WM.

Second, the gateway and unitary views have problems accounting for the well-established double dissociations of impairment of LTM but intact STM in some brain-damaged patients, while the converse is shown in other patients (reviewed in Baddeley, Kopelman, & Wilson, 2002). Among the latter are patients presenting with the phenomenon of pure representational unilateral spatial neglect who have an apparent impairment in one half of their visuospatial mental representation in the absence of visual sensory input. This is combined with intact visual perception, visual attention, and LTM for visual knowledge (e.g., Beschin, Cocchini, Della Sala, & Logie, 1997; Della Sala & Logie, 2002; Guariglia, Padovani, Pantano, & Pizzamiglio, 1993; Logie, Beschin, Della Sala, & Denis, 2005). If WM is a gateway between perceptual input and stored knowledge, and this gateway is impaired, then access to LTM to allow perception of the environment would necessarily also be impaired. These patients have severely impaired visuospatial working memory but have no problems in visually perceiving and interpreting their environment. Likewise, according to the unitary model, in which the contents of WM are the activated LTM representations, an impairment in the mental representation of images should necessarily be associated with an impairment in access to long-term visual representations. However, these patients show intact storage of long-term visual representations but have problems in forming temporary representations as visual images.

Empirical evidence for the workspace model in healthy adults comes, for example, from experiments that investigate the effects of irrelevant visual input (IVI) on visual short-term memory and visual imagery (e.g., Andrade, Kemps, Werniers, May, & Szmalec, 2002; Logie, 1986; reviewed in Logie & van der Meulen, 2008). One key assumption of this model is that imagery requires activation of information from LTM and would call on this activation to aid the generation of a mental visual image in WM. This generation process could involve activation of generic information from semantic memory or of a specific episode associated with a stimulus. In both cases the image generation would draw on a limited pool of resource for activation of stored knowledge, and this resource would be required whether driven bottom-up by perception or top-down through directed retrieval. A further assumption is that information already held in WM can be maintained and manipulated without necessarily requiring continued use of the LTM activation/generation process. IVI is predicted to disrupt image generation, because both require the limited pool of resource for activation of LTM. Visual short-term retention, however, is not expected to be affected because items can be maintained in WM independently of the perceptually driven activation of LTM.

Very different predictions follow from the gateway model. Because perceptual input is assumed to have direct access to working memory, IVI should interfere with short-term retention of any visual items being held. The gateway model would predict rather less disruption of image generation by IVI, given that the task need not involve any visual perceptual input with, for example, generating images from aural presentation of object names. The unitary model might predict that IVI would disrupt imagery more than short-term retention because imagery is more demanding and thus may be more prone to interference from any kind of attention-demanding secondary task. At the same time, visual short-term retention in the focus of attention might be relatively low demand and hence less susceptible to disruption by IVI. However, the unitary model does not make strong differential predictions, and could use similar arguments to account, post hoc, for the opposite pattern of results by suggesting that retention and rehearsal requires more attention than does generation of images.

Consistent with the workspace model, different types of visual perceptual input have been found to interfere with the use of the pegword mnemonic, a technique involving generation of interactive images. Disruption of pegword performance has been demonstrated by changing visual matrix patterns and changing plain coloured squares (Logie, 1986), a dynamic visual noise (DVN) display (e.g., Andrade et al., 2002; McConnell & Quinn, 2000, 2004; Quinn & McConnell, 1996, 1999, 2006), colour matching (Zimmer & Speiser, 2002), and line drawings (Andrade et al., 2002; Logie, 1986; Quinn & McConnell, 1996). Other imagery tasks have been demonstrated to be disrupted by DVN, such as visualizing a route on a climbing wall (Smyth & Waller, 1998), rating vividness of imagined scenes (Baddeley & Andrade, 2000), and animal size comparison (Dean, Dewhurst, Morris, & Whittaker, 2005). All these tasks depend crucially on the generation of mental images in visual working memory drawing on LTM representations.

In contrast, IVI seems to have no effect on visual short-term memory. For example, there is no disruption by DVN of memory for visual patterns or for unfamiliar Chinese characters (e.g., Andrade et al., 2002; Zimmer & Speiser, 2002). Quinn and McConnell (2006) reported disruption of the pegword mnemonic only when DVN is present during encoding or retrieval, but not during retention. This finding supports the workspace model, which would predict interference of IVI with the pegword mnemonic during those stages in which there is retrieval of information (i.e., generation of images) from LTM (encoding and retrieval) but not during retention of the images in LTM.

The effects of IVI cannot readily be explained in terms of general interference with limited attentional resources. Logie (1986) contrasted the interference effects of irrelevant pictures with those of irrelevant speech on a memory task using either a visual strategy (the pegword mnemonic) or a verbal strategy (rote recall). He found that irrelevant pictures interfered more with recall based on the pegword mnemonic than did irrelevant speech, whereas irrelevant speech interfered more with recall based on rote rehearsal than did irrelevant pictures. Quinn and McConnell (1996; see also Andrade et al., 2002) found a more general interference effect of irrelevant pictures, but reported selective effects of DVN on the pegword mnemonic, while irrelevant speech impaired only rote rehearsal. Whether irrelevant pictures have a general or specific effect remains to be resolved, and we address this issue in the experiment reported here. Nevertheless, there is no debate about the selective effects of DVN, and double dissociations of this kind are difficult to explain in terms of competing demands on a single, limited-capacity attentional system.

Andrade et al. (2002) proposed that separate processes underlie visual imagery and visual memory. They argue that visual imagery requires processing of visual representations in an active store (an "imagery buffer"), while retention of stimuli in visual short-term memory tasks uses a separate passive store, and that only the active store is susceptible to interference by IVI. This interpretation is consistent with the Logie (1995) workspace model and also with views expressed by Pearson (2001; see also Cornoldi & Vecchi, 2003) who proposed a distinction between an active visual buffer that manipulates conscious visual representations and a passive visual cache that temporarily stores visual representations. The above results and this interpretation are not, however, consistent with the original Baddeley and Hitch (1974; see also Baddeley, 2007) concept of the visuospatial sketchpad, which is thought to support both visual short-term memory and visual imagery.

The idea that visual imagery and visual retention are subserved by two separate stores has also been offered by Quinn and McConnell (2006), based on a model by Kosslyn (1994, 2005). They propose that there is a "visual buffer" that contains conscious visual images and that can actively maintain and manipulate these images, next to a visual cache, which holds interpreted information from LTM. Quinn and McConnell (2006) argue that irrelevant visual input has its disruptive effect due to direct access to the visual buffer structure, which is consistent with the view of WM as a gateway. In contrast, Andrade et al. (2002; Baddeley & Andrade, 2000) proposed that irrelevant visual input may reduce the subjective experience of images, without disrupting storage of the image representation in WM. They suggest that complex imagery tasks may be susceptible to interference from IVI because lack of vividness causes participants to adopt less effective strategies, or to spend too long on components of the task that require imagery.

The Andrade et al. (2002) interpretation is compatible with the workspace model, with DVN disrupting the process of generating visual images from LTM, perhaps because DVN introduces noise into the generation process for complex images based on aurally presented materials. Alternatively, the participants might be attempting to detect familiar patterns in the DVN displays, despite instructions to ignore the display. However, DVN might only be disruptive when the concurrent image generation process is fully occupied—for example, generating complex mnemonic images. In the present experiment we explored the potential conflict between activation of representations in LTM by irrelevant visual input and the process of generating simple images from LTM or retaining recently presented visual material. To ensure that LTM representations were likely to be accessed, in the experiment reported here, we used irrelevant pictures of recognizable objects (Logie, 1986) rather than DVN.[1] This also allowed assessment of whether irrelevant pictures produce general interference or specific interference.

[1] A pilot experiment using these generation and retention tasks showed no effects of DVN on either task (Van der Meulen, 2008). Others have also failed to replicate the effects of DVN on imagery tasks (e.g., Pearson, Logie, & Gilhooly, 1999; Zimmer & Speiser, 2002). A detailed discussion of why this might be is beyond the scope of this paper but is discussed in Logie and van der Meulen (2008).

Finally, a common alternative to DVN as a secondary task disrupter in visuospatial working-memory research is hand tapping, following a set spatial pattern such as a figure of eight layout on a table or on an array of keys. Tapping tasks of this kind have repeatedly been shown to disrupt visuospatial working memory but not verbal memory (e.g., Andrade et al., 2002; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Engelkamp, Mohr, & Logie, 1995; Salway & Logie, 1995). They are generally employed to disrupt spatial processing (e.g., Quinn & Ralston, 1986; Smyth & Scholey, 1994). However, tapping is typically unseen and so involves no visual input, yet requires motor planning and execution as well as keeping track of which location has just been tapped and which location should be next. According to the unitary model, this task would be demanding of attention, and of temporary memory, so it should act as a general disrupter of any other attention-demanding task. However, the fact that it is unseen suggests that it should have very little disruptive effect on the operation of a gateway type of store that is holding material that has been presented visually. In contrast, the workspace model would expect its disruptive effects to be specific to the operation of the temporary visuospatial memory system and not of the image generation process.

In the experiment reported here, we aimed to compare the three models of the interaction between WM and LTM directly by testing differential predictions as to whether irrelevant visual input will interfere with visual short-term memory and/or with visual imagery. Dual-task methodology was used to study the effects of viewing irrelevant pictures and of tapping a pattern on each of two tasks, one involving the generation of mental visual images from auditory input, and one involving short-term retention of visual properties of stimuli.

The gateway model would predict substantial interference of visual retention in WM by irrelevant pictures, because perceptual input is assumed to have direct access to WM. There is not a clear prediction as to the effect on visual imagery with auditory input, or of the effect of tapping on visual retention or visual imagery, although the use of different input modalities in these experimental conditions should minimize disruption in the gateway. The unitary model might predict more disruption of imagery than of retention by either secondary task, because imagery generation could be argued to be more attention demanding and therefore more prone to disruption regardless of the nature of that disruption. Because pattern tapping has several cognitive requirements for motor planning and keeping track, it should be more attention demanding than passive viewing of irrelevant pictures and therefore should be more disruptive of both primary tasks. The workspace model would predict selective effects of the secondary tasks. Viewing irrelevant pictures should disrupt image generation from auditory input because both require the activation of representations within LTM, but be largely unaffected by concurrent tapping, which requires no LTM access. Visual short-term retention should be able to operate without interference from irrelevant visual input, but is likely to be disrupted by a concurrent unseen pattern tapping task that relies on temporary memory for position as well as motor control.

Method

Participants and design

Participants were 48 (30 female; 18 male) native English-speaking students from the University of Edinburgh, mean age 20.83 years ($SD = 2.41$). A $2 \times 2 \times 2$ mixed design was used; each participant performed both main tasks (retention and generation) in two conditions (control and interference). Half of the participants were given irrelevant pictures as the interference task, and half of the participants were given pattern tapping. The order of presentation of tasks and conditions was counterbalanced across participants within each group.

Materials and stimuli

In the *retention task* participants had to remember identity, letter case, and presentation order of four visually and sequentially presented letters (Logie, Della Sala, Wynn, & Baddeley, 2000). Letters were taken from a set of six visually dissimilar letters with visually dissimilar upper- and lower-case forms (Dd; Hh; Ll; Mm; Qq; and Rr). They were presented one at a time in Arial font size 24 in the centre of a computer screen in either upper or lower case for 500 ms each, with an interstimulus interval of 500 ms. An example display might be "d–M–Q–r". Case information could be encoded as visual shape and size of the letters. Participants performed articulatory suppression during presentation and retention, repeating "the" three times per second. With visual presentation, articulatory suppression is assumed to prevent phonological coding, increasing the likelihood of visual coding (Hitch, Woodin, & Baker, 1989). Participants were explicitly instructed to try and remember the letters visually, not as letter names. Logie et al. (2000; Saito, Logie, Morita, & Law, 2008) demonstrated poorer recall of visually similar than of visually dissimilar letters, both with and without articulatory suppression. This visual similarity effect was robust and was replicated in different experiments, suggesting the use of visual codes for retention of visually presented letter sequences. Finally, because each trial comprised a selection of four items from a set of six, there were multiple repetitions of individual letters across trials, with participants being required to retain the order of presentation for each trial. As such, item-based information such as stored previous knowledge about the letters would not have been helpful in performing the task.

A total of 36 sequences of four letters with mixed upper- and lower-case forms were constructed. Across sequences, each letter appeared an equal number of times in its capital and lower-case form, in each serial position and in the control and interference condition, and never more than once in each sequence. Two different versions of the set of 36 sequences were made, with participants assigned randomly to one of these. There were 18 sequences in the control condition and 18 in the dual-task condition, with allocation of stimulus sets to condition counterbalanced across participants.

A 1-s blank blue screen display indicated the start of the trial and was the cue to start articulatory suppression. After a 15-s retention interval, recall was prompted by a tone and a blank red screen. Participants stopped articulatory suppression and were requested to recall the letters by writing them on a response sheet comprising four boxes arranged horizontally, with a horizontal line drawn through the centre of each box to avoid ambiguity as to whether a letter was written in its lower-case or upper-case form.

In the *generation task* participants listened to a series of 13 random letter names presented from digital audio recordings at 1/s. For each letter, they had to generate an image of the appearance of the upper-case version of the letter as it appears on a standard computer keyboard and to decide whether it matched a criterion based on its visual characteristics. The computer keyboard was kept out of sight of the participant. The criterion was different for each of the nine letter series for a given condition (control or with irrelevant pictures)—namely, horizontal and vertical symmetry, curves, straight lines, enclosed spatial areas, similar upper- and lower-case forms, parallel lines, single line, and right angles. They were asked to respond orally with "yes" or "no" after each letter, depending on whether or not that letter met the specified criterion. Although there were fewer trials in each condition of this task than there were in the retention task, the number of data points available for analysis was greater. In this task there were $9 \times 13 = 117$ data points in each condition, whereas there were $18 \times 4 = 74$ data points in each condition of the retention task.

Each trial contained either the letters A–M in random order or the letters N–Z in random order, and these letter sets alternated between trials. No letter was used more than once with any given criterion, and each letter was used the same number of times in each condition. Each criterion was used only once in each condition (control and with interference task). Three different versions of combinations of letters and criteria were created, and participants were randomly assigned to one of the three versions. These procedures for selecting materials helped ensure that each trial would require activation of stored information in LTM about the letter presented, and participants could not respond on the basis of responses given on previous trials.

Interference tasks. The irrelevant pictures used as the interference task for half of the participants consisted of line drawings from Snodgrass and Vanderwart (1980). In each trial, a series of 13 pictures was presented for 300 ms each with an interstimulus interval of 700 ms. Pictures were presented in the middle of a computer screen and were between 10 cm and 15 cm in width and between 10 cm and 15 cm in height. The presentation of the pictures in the interference condition of the generation task coincided with the auditory presentation of the letters. In the interference condition of the retention task, presentation of the pictures commenced 500 ms after presentation of the fourth letter for each trial.

The tapping task used with the other half of the participants involved tapping with one finger of the preferred hand each of 9 keys in a 3 × 3 arrangement, following a figure-of-eight pattern. Tapping speed was 2 per second, and participants were required to look at a blank computer screen while tapping and not at their hand. The sequence of keys tapped and the intertap intervals were recorded. In the retention task, tapping commenced immediately after presentation of the fourth letter until the end of the retention interval. In the generation task, participants were required to tap during the entire trial.

Procedure

Participants were tested individually in a quiet room with no windows and a minimum of visual distractors around the room. Stimuli for the image generation task were presented through speakers next to the participant. The irrelevant pictures and the stimuli for the retention task were presented on the screen of a PC desktop computer, with a viewing distance of approximately 50 cm. In the control conditions participants were instructed to look at a blank screen on the computer monitor. Participants received two practice trials before each condition of the retention task and one practice trial before each condition of the generation task. Time for recall was unlimited in the retention task. The experimenter sat next to the participant throughout the experimental session to check compliance with the task-specific instructions.

Results

Performance on the retention task was taken as the proportion of the maximum number of correctly recalled letters in correct case and serial position in each trial. For the generation task this measure was the proportion of maximum number of correct judgements in each trial. Mean data are shown in Table 1.

Performance levels of both tasks were well below ceiling and above floor, and they were very similar. The effect of the interference tasks was tested in a three-way repeated measures analysis of variance (ANOVA) with group (pictures vs. tapping as interference), task type (retention vs. generation),

Table 1. *Mean proportions of correct responses for the retention and generation tasks without and with irrelevant pictures or tapping as the interference task*

	Pictures				*Tapping*			
	Control		*Interference*		*Control*		*Interference*	
Main task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Retention	.73	.18	.70	.18	.73	.17	.61	.16
Generation	.84	.07	.77	.09	.76	.08	.76	.08

and experimental condition (control vs. interference) as the independent variables. The analysis revealed a marginal effect of group, $F(1, 46) = 3.67$, $p = .06$, a main effect of task type, $F(1, 46) = 15.10$, $p < .001$, and a main effect of condition, $F(1, 46) = 18.32$, $p < .001$. None of the two-way interactions was significant, but crucially, there was a significant three-way interaction between group, task, and condition, $F(1, 46) = 7.29$, $p < .01$. Post hoc pairwise comparisons between means using Newman–Keuls tests showed that retention of visually presented letters was significantly disrupted by tapping ($p < .001$) but not by irrelevant pictures ($p = .5$), while image generation from aural presentation of letter names was significantly disrupted by irrelevant pictures ($p < .05$) but not by tapping ($p = .85$).

There was no impact of irrelevant pictures on the letter retention task. However, given the impact of tapping on letter memory, we further examined for the Group 2 data only whether there were differential effects of tapping on three different measures of recall performance: (a) recall of letter identity, (b) recall of the serial order of the letters, and (c) recall of letter case. These specific recall performance levels in the control and interference condition for Group 2 are shown in Figure 1.

Recall of letter identity independently of serial position and letter case was significantly affected by concurrent tapping, $F(1, 23) = 9.85$, $p = .005$, as were recall of letter case independently of letter identity, $F(1, 23) = 25.21$, $p < .001$, and recall of letter case and letter identity, $F(1, 23) = 22.73$, $p < .001$. The effect on recall of serial order independently of letter case was marginal, $F(1, 23) = 4.20$, $p = .052$. In sum, the disruptive effects of tapping were clearest for measures linked with letter identity and letter appearance.

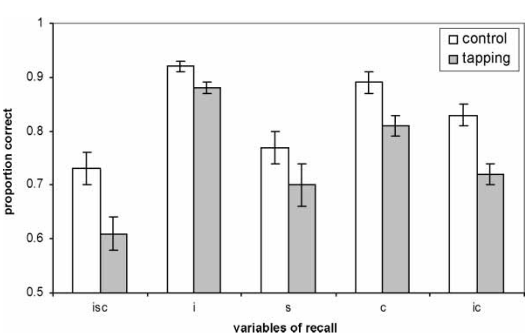

Figure 1. *Mean proportion of correct responses for different measures of recall performance in the control and interference conditions of the retention task in Experiment 2. i = letter identity, s = serial order, c = letter case.*

There was no measure of performance for irrelevant pictures, but it was possible to compare tapping performance when combined with letter retention or letter image generation, on the basis of three measures: (a) accuracy of maintaining the tapping pattern, (b) mean intertap intervals, and (c) variance in intertap intervals. Errors comprised omissions or extra taps in the pattern, or reversals in tapping direction. The mean number of errors did not differ between the retention task and the generation task, $F(1, 23) = 0.94$, $p = .34$. Mean intertap interval was close to the instructed speed (0.49 s for retention, 0.44 s for generation) and did not differ between tasks, $F(1, 23) = 2.42$, $p = .13$. Variance in intertap intervals differed significantly between tasks, $F(1, 23) = 4.95$, $p < .05$, indicating that tapping was more irregular during image generation than during retention.

Discussion

Concurrent viewing of irrelevant pictures significantly disrupted image generation, but had no effect on visual short-term retention. These results are consistent with previous findings that perception interferes with visual imagery, but not with visual short-term memory (e.g., Andrade et al., 2002). The gateway model cannot readily account for this data pattern, given that the results suggest that irrelevant perceptual input does not have direct access to visual working memory, where it would disrupt retention of items for items to-be-remembered. The workspace model proposes that items can be maintained in visual WM, independently of perceptually driven activation of LTM. In this view, irrelevant pictures will not interfere with retention, but will interfere with image generation, which also involves activation of LTM, as was found in this experiment.

The unitary model could also account for this first half of the experiment by assuming that the generation task is more demanding of attention than is the retention task and is therefore more prone to any type of interference. However, this interpretation has difficulty with the results of the other half of the experiment, because in this case, the image generation task is completely unaffected by an attention-demanding secondary task—namely, pattern tapping. In contrast, the retention task was disrupted by pattern tapping but not by irrelevant pictures. This three-way interaction shows that the secondary task interference effects are specific to the particular combination of tasks and are not driven by demands on general-purpose, limited-capacity attentional resources.

The workspace model can account for the results of the three-way interaction by suggesting that irrelevant perceptual input in Experiment 1 disrupted image generation because both compete for activation of LTM representations. Tapping disrupted visual short-term retention, according to the workspace view, because keeping in mind progress with movement around the tapping pattern, and maintaining the case form and identity of the letters, both required visuospatial WM. The fact that performance levels of the tapping task did not differ much between the retention and generation task makes it unlikely that participants sacrificed tapping performance in favour of image generation. There was more variability in tapping during the generation task than during the retention task. This could be attributed to possible response output conflicts, given that the generation task required an oral response for each letter, and this might have slightly delayed some of the tapping responses, rather than any conflict at the cognitive processing level.

It is interesting to see that in the retention task, tapping appeared to interfere primarily with visual features, specifically letter identity and case-form. The effect on memory for serial order of the letters was marginal, so leaves open the debate as to whether serial order can be retained by modality-specific systems or by some amodal serial order mechanism (e.g., Logie et al., 2000; Saito et al., 2008; Smyth, Hay, Hitch, & Horton, 2005; Ward, Avons, & Melling, 2005). Nevertheless, the general pattern of results is in line with the predictions of the workspace model; the tapping task draws on visuospatial temporary memory to maintain the tapping pattern and thus interferes with retention of the visual characteristics of the letters.

Taken together, the results we have reported here fit best with the predictions of a model that views WM as a system that is functionally and structurally separate from LTM, and in which perceptual input is thought to activate LTM before having access to WM. The gateway model, which assumes that perceptual input has direct access to WM, is unable to account for the finding that irrelevant visual perceptual input did not affect visual short-term retention, and it makes no clear predictions about the impact of pattern tapping. The unitary model can account for the results of each half of the experiment separately by hypothesizing that one task is more attention demanding than the other. This explanation, however, runs into difficulties when looking at the overall pattern of results, which suggest differential specific effects rather than general interference effects. The workspace model offers an account for the observation that irrelevant visual perceptual information appears to disrupt visual imagery but not visual short-term memory, while tapping disrupts visual short-term memory but not imagery. Image generation involves the activation of LTM, which is seen in this model as part of the process of perception. Short-term visual memory is assumed to rely on a working-memory "workspace" independently of the process of activation of LTM.

One caveat comes from results in the literature that appear to be inconsistent with those reported here, notably demonstrations of detrimental effects of irrelevant visual input on what are described as visual short-term memory tasks (e.g., Della Sala et al., 1999; McConnell & Quinn, 2004), or a lack of effect of irrelevant visual input on imagery tasks (e.g., Avons & Sestieri, 2005). One possible interpretation of the former set of findings in terms of the workspace model is that participants may have used LTM strategies for these visual memory tasks. In the McConnell and Quinn (2004) study, participants were specifically instructed to generate a conscious, bizarre, and meaningful visual image for each list item, thereby requiring the generation of associated representations in LTM during encoding. The list lengths for recall greatly exceeded the widely assumed capacity limits of a short-term memory system, and so it is likely that the images were maintained in LTM, and those LTM representations were reactivated during retrieval. As such, there would be very little, if any, memory load on a visuospatial memory system, but a substantial load on image generation from LTM. The perceptual interference tasks may then have caused disruption because they also involve LTM activation from perceptual input (for a more detailed discussion see Logie & van der Meulen, 2008). In the letter retention task used in the current study, the requirement for articulatory suppression and the repeated use of the same items across trials would have made it very difficult to use information about the letters stored in LTM to support performance, leading to greater demands on temporary memory. The abstract paintings in the Della Sala et al. (1999) study were presented on paper cards, held in front of the participant by the experimenter. The same 12 cards were presented in each retention interval in random order. This quick manual changeover of cards could have evoked large eye movements by participants, making this visual interference material particularly disruptive (see e.g., Pearson & Sahraie, 2003; Postle, Idzikowski, Della Sala, Logie, & Baddeley, 2006). Moreover, Della Sala et al. used different matrix patterns across trials and did not use articulatory suppression, raising the possibility that several of the matrix patterns could have resembled familiar objects or patterns, thereby activating LTM stored knowledge for those patterns. The argument that it is extremely difficult to avoid recognizable patterns in square matrix arrays is discussed by Broadbent and Broadbent (1981; see also Logie, Zucco, & Baddeley, 1990).

An explanation for the lack of effect of irrelevant visual input in the Avons and Sestieri (2005) study is that their task did not involve the generation of images based on the activation of LTM representations. It was a "cumulative imagery task", in which participants were instructed to form an image of a matrix pattern, by mentally adding sequentially presented cells. This would have been heavily reliant on temporary memory for partially completed patterns and was very different from the task used by Della Sala et al. (1999) in which the entire pattern was presented visually and simultaneously.

In summary, there are major differences between the tasks used in previous studies and those reported in the present paper that could have given rise to the patterns of results that apparently contrast with those reported here. However, these accounts would merit further scrutiny in future studies, with clear specification of the cognitive requirements of the tasks in each case.

The results of these experiments are not consistent with the interpretation of Quinn and McConnell (2006) that imagery is served by a "visual buffer", which is separate from the visual cache used for retention, and that only the buffer is susceptible to interference. According to this account, the spatial tapping task should have disrupted the image generation task, which it did not. The suggestion of Andrade et al. (2002) that irrelevant visual input reduces the subjective experience of images without disrupting storage in WM is not incompatible with the workspace model. Disturbance of the subjective experience of the letters in the generation task may well have contributed to the interference effect that irrelevant pictures had on judgements about the visual characteristics of those letters.

Another possible explanation for the differential findings for irrelevant pictures is that in the generation task the pictures were presented simultaneously with auditory presentation of the stimuli, whereas in the retention task presentation of the pictures occurred during a retention interval for the letters. This difference was of course essential for the hypotheses being tested given that we are arguing for a dissociation between image generation (with no memory requirement) and temporary memory. The pictures might therefore have disrupted stimulus encoding by dividing attention during encoding, rather than having a selective effect on image generation. If this were the case, then the tapping task should also have divided attention at encoding. However there was no evidence that tapping disrupted image generation, even though tapping was required throughout presentation of the letters of the generation task, and the specific tapping task used here required the constant monitoring and control of movement.

In conclusion, the experiment reported here offers a pattern consistent with the workspace model of working memory, specifically that visual perceptual input activates stored representations in LTM prior to the product of that activation being transferred to and maintained in a separate mental workspace for visuospatial material (Logie, 1995, 2003; Logie & van der Meulen, 2008). Results also are consistent with the argument that the process of generating images of stored representations may be considered as a separate process and may involve a different mechanism from temporary storage of visuospatial material.

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