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Dissociation between appearance and location within visuo-spatial working memory.

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Abstract

Previous research has demonstrated separation between systems supporting memory for appearance and memory for location. However, the interpretation of these results is complicated by a confound occurring because of the simultaneous presentation of objects in multiple-item arrays when assessing memory for appearance and the sequential presentation of items when assessing memory for location. This paper reports an experiment in which sequential or simultaneous modes of presentation were factorially manipulated with memory for visual appearance or memory for location. Spatial interference (tapping) or visual interference (dynamic visual noise) were presented during retention. Appearance versus location interacted with the type of interference task, but mode of presentation did not. These results are consistent with the view that different subsystems within visuo-spatial working memory support memory for appearance and memory for location.

Dissociation between appearance and location within visuo-spatial working memory.

There is evidence to suggest that visuo-spatial working memory (VSWM) can be subdivided into two systems (Logie, 2003). Much of this evidence comes from behavioural experiments. For example, Logie and Marchetti (1991) presented participants either with an array of colour shades or with a series of squares shown one after the other in different random locations. During a retention interval, participants either watched a blank screen, performed a spatial tapping task, or viewed irrelevant line drawings of objects. Memory for the series of locations was impaired by interpolated tapping but not by random pictures. In contrast, memory for colour shades was impaired only by interpolated pictures. Della Sala, Gray, Baddeley, Allamano and Wilson (1999) reported a broadly similar pattern of results, using the Visual Patterns Task (VPT) which involves remembering an abstract matrix array presented as a single pattern, and a version of the Corsi blocks task which involves memory for a sequence of movements to objects in an array. A study by Hecker and Mapperson (1997) confirmed this pattern. Finally, Logie and Pearson (1997) reported that between the ages of 5 and 12 years, the developmental increase in task performance on the VPT was substantially faster than that for the Corsi blocks task, and the tasks correlated poorly within each age group. As a consequence of this type of evidence, two components of visuo-spatial working memory have been proposed, a visual cache thought to store visual appearance of a stimulus array, for example colour, shape or pattern, and an inner scribe, thought to retain spatial information such as locations and movement between locations (Logie, 2003).

Basing models of VSWM segregation on tasks such as the Corsi task and the VPT raises an important question, because a trial for the Corsi task involves presenting a sequence of movements, whilst a trial for the VPT involves simultaneous presentation of an array of squares that form a pattern in a matrix. Therefore, differences between the tasks in the experiments described above could stem from either the requirements to remember locations of items versus their shape, pattern or colour, or could stem from differences between systems that process respectively sequential and simultaneous modes of presentation.

A number of studies using different procedures and tests support a distinction between memory for appearance and memory for location of an item. Functional neuroimaging studies have suggested that different anatomical areas are implicated in visual and spatial memory tasks. For example, location memory has been shown to cause higher levels of activation in dorsal frontal areas than does memory for faces (for a recent discussion on working memory localisation and prefrontal cortex see Sala & Courtney, 2007). Xu and Chun (2006) claimed that the superior intraparietal sulcus and lateral occipital complex are involved in memory for object identity, whilst the inferior intraparietal sulcus is recruited by spatial processes. Data which speak to the location/appearance dichotomy also come from cognitive psychology and neuropsychology: Tresch, Sinnamon and Seamon (1993) observed that dot location recall was selectively disrupted by a movement discrimination task, while recognition memory for object forms was disrupted by a colour discrimination task, a result replicated by Klauer and Zhao (2004). Darling, Della Sala, Logie and Cantagallo (2006) identified a double dissociation between two brain-injured patients, one with a deficit in memory for location and one with a deficit in appearance memory, in a task where only a single item was to be remembered. These studies argue for an appearance-location based segregation of VSWM.

In contrast to the above, studies of child development suggest that the distinction between spatial and visual systems may reflect processing of simultaneous and sequential information in different systems. Pickering, Gathercole, Hall and Lloyd (2001) assessed children of different ages on a visual matrix pattern memory task (based on the VPT) and a maze memory task (similar to the Corsi task). They found that developmental trajectories of performance on simultaneous presentations of both tasks were different from the trajectories when sequential presentation was used. Pickering *et al.* (2001) argued that their results were best characterised by a static (simultaneous) versus dynamic (sequential) distinction. Cornoldi and Vecchi (e.g. 2003) have argued that the distinction between VSWM subcomponents might be more on a continuous dimension of passive and active task requirements. These distinctions are broadly consistent with the visual cache/inner scribe concepts proposed by Logie (2003), although the precise characteristics of each distinction differ between groups of researchers.

Pickering *et al.* (2001) demonstrated the importance of evaluating the impact of sequential or simultaneous presentation when multiple items are remembered. Whilst it is clear from Tresch *et al.* (1993), Klauer and Zhao (2004) and Darling *et al.* (2006) that an appearance-location segregation is present in memory for a single stimulus, the case is less clear when memory for multiple items is considered, and consequently the role of mode of presentation (simultaneous or sequential) should not be overlooked.

Very little research has directly and systematically addressed the question as to whether sequential versus simultaneous presentation or appearance-versus-location is the key defining principle of separable VSWM subsystems. Zimmer, Speiser and Seidler (2003) reported that the explicit requirement to remember sequential order in the Corsi blocks task was unrelated to the size of tapping-related interference effects, arguing that participants encoded sequential features of the stimuli irrespective of whether or not they were given explicit instructions to do so. Xu and Chun (2006) found some evidence that sequential or simultaneous mode of presentation did not affect their results. This contrasts with the Pickering *et al.* (2001) result which suggested a key role for the sequential/simultaneous manipulation but not for appearance. However, Xu and Chun's manipulation was not a definitive test because the sequential/simultaneous contrast was manipulated between a single display of 4 items versus 2 consecutive displays of 2 items each.

In the current article we report the results of an experiment which systematically manipulated sequential versus simultaneous presentation, and appearance versus location of stimulus sets in a temporary memory task in which multiple items were remembered. A direct and systematic comparison in which these experimental conditions are factorially manipulated has not previously been reported. The experiment we report here used a task in which exemplars of the letter P were presented in different fonts (varying appearance) and in different locations, either simultaneously or successively. The task was to remember either the appearance or the location of stimulus items. The extent to which memory performance was influenced by the mode of presentation was assessed using a dual task interference paradigm, with either spatial interference or visual interference during a retention interval. One of the interference tasks involved tapping a sequence of locations, a procedure shown in previous studies to disrupt retention of sequential spatial material such as the Corsi blocks (e.g. Della Sala *et al.*, 1999; Smyth & Scholey, 1994). Dynamic Visual Noise (DVN - McConnell & Quinn, 2003), was used as the other interference task. This comprises a display of dots which flicker randomly at a predetermined rate. Although previous studies have shown that DVN does not affect a range of visual short-term memory tasks (e.g. Andrade, Kemps, Werniers, May &

Szmalec, 2002; Zimmer & Speiser, 2002), McConnell and Quinn (2003) demonstrated that DVN disrupts memory for visual detail, and therefore it might be expected to affect memory for the specific font in which a letter appears.

Method

There were 192 participants in this study (52 male), with a mean age of 23 years (range 17-52, s.d. = 5 months).

The ‘S’ and ‘K’ keys on the computer keyboard were labelled as ‘S’ame and ‘D’ifferent for participant response. A 15 inch monitor set to a screen resolution of 800 x 600 pixels was used to display the stimuli. The spatial interference task involved a 3 x 3 array of square buttons, located on the side of the computer keyboard for the participant’s dominant hand. The button array was shielded from the participant’s view.

The design incorporated three between groups factors, namely memory condition (remember appearance or location), type of interference task during the filled delay (tapping or DVN), and mode of presentation (sequential or simultaneous presentation). Retention condition (filled or unfilled), was included as a repeated measures factor.

All trials began with a fixation cross, presented in the centre of the screen, which immediately preceded the presentation array comprising 30 white squares with each square subtending 1.6° visual angle. These squares were distributed randomly across a screen area subtending 25.3° x 17.2° visual angle, and none of the squares touched or overlapped.

In the presentation phase of simultaneous appearance trials each of three squares of the array contained a letter P in a different font. These were drawn from a library of 433 fonts. The display was present for 1.5 s (.5 s per square). Participants were instructed to try and remember the appearance of the letters, but that they need not recall the location. Figure 1 shows an example display.

(Figure 1 about here)

The presentation phase of simultaneous location trials was the same except that four items were presented for a total of 2 s (.5 s per square), and participants were instructed to remember the location of the letters, but that they need not recall the appearance. Pilot work indicated that 4 items in this condition led to similar levels of performance as were obtained with 3 items in the simultaneous-appearance condition.

In the presentation phase of sequential appearance trials, three different letter P items were presented one after the other each in one of 3 different squares of the presentation array. Each letter was shown for .5 s before it disappeared, followed immediately by the next letter in a different location. Participants were instructed to remember the appearance, but not the location, of the letters. They were not required to remember the sequential order of presentation.

In the sequential location trials, the presentation procedure was exactly the same as for the sequential appearance condition, except that 4 items were presented instead of 3 and that participants were instructed to remember the location of the letters, irrespective of their appearance. Again, participants were not required to remember the sequential order of presentation.

After presentation, in the unfilled condition the screen remained blank for 15.5 s, followed by the response phase. In the filled condition, during the 15.5 s retention interval, participants carried out the allocated interference task.

DVN was implemented as follows. Immediately after the offset of the target stimuli, an 80 x 80 array of black and white dots appeared on the screen. This matrix subtended a 9.6° x 9.6° visual angle. The dots flickered rapidly from black to white or vice versa, at an average rate of 300 dots per second. Participants were instructed to watch the dots as they changed.

For the interpolated tapping task, during the 15.5 s retention interval, participants had to tap the keys of the keypad in a figure-of-eight pattern, attempting to tap at a rate of one key per second, starting with the top left key and repeating the pattern until the response screen appeared.

Following the retention interval, the original 30 squares were presented in the same locations as in the presentation phase. In the two simultaneous conditions, the memory test display comprised only one probe letter P. On 25% of the trials this item matched the location and appearance of one of the previously presented items. On 25% of trials, the probe letter matched the location but not the appearance of one the targets. On 25% of trials, the probe matched the appearance of one target but was shown in a different location from any of the targets. On the remaining 25% of trials, both location and appearance were different from any of the targets. Participants in the appearance condition were asked to indicate whether or not the probe item was of the same appearance as one of the targets irrespective of location. In the location condition participants were asked to indicate whether or not the probe was in the same location as one of the target items irrespective of appearance.

In the sequential presentation conditions performance might have been driven by a single item recency effect. To help avoid this, the test display comprised the same array of letters P as in the study array, but shown simultaneously, and with one item (the probe item) manipulated. The single probe item was in the same location and of the same appearance as one of the items seen at presentation on 25% of trials; it was in the same location but of a different appearance on 25% of trials; in a different location but of the same appearance on 25% of trials, and of both different location and appearance on 25% of trials. Participants in the appearance memory condition were asked to indicate whether all of the three visible items were of the same appearance as the to-be-remembered items or if any of them was different, irrespective of location. Participants in the location memory condition were asked to indicate if all four of the probe items were in the same locations as the previously presented items or if any was different, irrespective of appearance.

Each participant carried out two experimental sets of 24 trials, one filled and one unfilled, with the order being counterbalanced across participants. Each set of 24 experimental trials was preceded by 12 practice trials, including the interference task when relevant.

Results

Means of raw accuracy scores are presented in Table 1. Raw scores do not take account of individual differences in baseline ability, and therefore an analysis was carried out on percentage accuracy scores, calculated by expressing each participant's total score on filled delay items as a percentage of their score on unfilled delay items. This removed one factor (filled/unfilled delay) and simplified the analysis. These scores are presented in the bottom row of Table 1. Percentage accuracy was entered into a 2 x 2 x 2 ANOVA, in which memory condition, presentation mode and interference task were factors. The main effects for each of the three variables were non significant, and only the main effect of memory condition approached significance ($F(1,184) = 3.38$, $p < .07$, MSE = 196.41, $\eta^2 = .02$). The interaction (see Figure 2) between memory condition and interference task was highly significant ($F(1,184) = 16.41$, $p < .001$, MSE = 196.41, $\eta^2 = .08$). All other interactions had small effect sizes and were far from being significant.

(Table 1 around here)

(Figure 2 around here)

Figure 2 shows the pattern of means of percentage accuracy for the significant interaction between memory condition and interference task. Directional post-hoc (Fisher's LSD test) comparisons were employed to evaluate the predictions of the appearance/location model of segregation. This model makes specific predictions that location memory will be more impaired by tapping than by DVN, and that appearance memory will be more impaired by DVN than tapping, therefore a directional post-hoc test is appropriate. Location memory performance was more impaired when participants carried out tapping (mean =84.75%, s.d. = 11.38) than when they observed DVN (mean= 96.15%, s.d. = 14.49: p < .001). Appearance memory performance was more impaired when participants observed DVN (mean= 91.67%, s.d. = 15.01) than when they carried out tapping (mean= 96.67%, s.d. = 14.49: p = .04).

Discussion

There was a significant two-way interaction between interference task and memory condition. This interaction was in line with the predictions of appearance-location segregation, namely that DVN selectively disrupted appearance memory and tapping selectively interfered with location memory. In contrast, mode of presentation did not significantly interact with memory condition or with type of interference. This pattern provides an experimental double dissociation between appearance and location memory, irrespective of presentation mode. Although not reported here for the sake of conciseness, RT latencies were recorded to ensure that the patterns observed from accuracy were not a consequence of systematic speed-accuracy trade-offs. There was no evidence to suggest that this was the case.

The dissociation between appearance and location might be interpreted as being consistent with the dissociation between the use of the dorsal or of the ventral pathway in the two visual systems model of posterior cortical visual processing (Ungerleider & Mishkin, 1982; Milner & Goodale, 1995). However, that is a model of perceptual processing whilst the focus of the current paper is specifically on memory over short intervals. Courtney, Ungerleider, Keil and Haxby (1996) reported evidence from PET studies showing differential patterns of activation observed in pre-frontal cortex associated respectively with memory for location and memory for object identity. Like the results of the current study, this evidence is consistent with the model of an appearance-location dissociation within VSWM that is rather different from the dichotomies linked with perceptual processing.

The sequential Letter P tasks involved retaining location information presented sequentially but they did not require participants to retain the order of the presentations. The experiments by Tresch *et al.* (1993), Klauer and Zhao (2004), and Darling *et al.* (2006) also did not require retention of order. In contrast, evidence supporting simultaneous-sequential based segregation, such as that from Pickering *et al.* (2001), involves explicit memory for temporal order. It is possible that different systems are recruited when memory for temporal order is required (e.g. Avons & Mason, 1999; Rudkin, Pearson & Logie, 2007; Smyth, Hay, Hitch & Horton, 2005).

These results are challenging to static-dynamic (e.g. Cornoldi & Vecchi, 2003; Pickering *et al.*, 2001) interpretations of VSWM segregation which imply that DVN, but not tapping, should impair memory for statically presented locations, while tapping, but not DVN should impair appearance memory for sequentially presented items. This is quite different to what we report here. It is possible, however, that the observed pattern of interference occurs because the location memory task, whether presented statically or dynamically, recruits a sequential spatial rehearsal process, which is impaired by tapping, whilst remembering visual appearance recruits a non-spatial process, which is impaired by irrelevant visual interference. Zimmer *et al.* (2003) argued that a spatial rehearsal process termed 'spatial marking' is required in order to maintain linkages between spatial locations and temporal order, and that this rehearsal is impaired by dual tasks (such as tapping) which require spatial attention to be directed elsewhere. In our task, there was no need to maintain linkages between spatial locations and order. However, Zimmer *et al.* (2003) observed that concurrent tapping resulted in the same level of interference whether or not participants were required to remember the sequential order for a set of Corsi like stimuli. This suggested that the sequential order of presentation was being remembered by participants regardless of the task instructions. It is possible that a similar account could apply to our own results: the nature of our simultaneous stimuli, comprising letters distributed across white squares against a black background, might have induced participants in the sequential presentation conditions to encode the order of the spatial locations, even though it was not an explicit task requirement to do so. However, the lack of an interaction between the presentation mode and type of interference task indicates that this was unlikely to be the case: memory encoding was unaffected by mode of presentation.

We report here interference effects of DVN on visual memory tasks. Previously DVN has been observed to cause interference during encoding (imagery generation), retrieval (imagery retrieval), and conscious visual image maintenance in explicitly imagery-based tasks. Therefore McConnell and Quinn (2003) argued that DVN provides direct access to visual working memory. However, to date there have been no published reports of DVN selectively interrupting performance on a visual memory task that was not reliant on imagery. Andrade *et al.* (2002) failed to find any effects of DVN as an interference stimulus in a series of experiments which addressed visual memory, rather than visual imagery. Avons and Sestieri (2005) were also unable to find interference effects of DVN on visual memory tasks. Zimmer and Speiser (2002) found no interfering effects of irrelevant visual displays on visual short term memory. The observation of selective impairment of performance on the Letter P task visual condition by DVN in the current experiment is therefore novel. One possible explanation of this finding is that DVN causes interference effects that are quite small, and therefore are only apparent when the memory task demands are high. Our task does requires accurate memory of the appearance of letter P stimuli to a high level of detail. This might require continual generation of visual images to maintain the representation. However, Andrade *et al.*'s (2002) Experiment 5 in particular was explicitly designed to increase memory demands by using four Chinese characters. Although in the current experiment participants had to remember only three letter P stimuli, these varied in quite subtle ways (e.g. presence / absence of a serif; italicisation, etc.) whereas Chinese characters can vary in a number of ways which affect the gross spatial orientation of the constituent elements. It is thus possible that the Chinese characters were easier to remember than our letter P stimuli. It is not possible to be certain from the current experiment whether the observed DVN interference effect represents 'direct access' to visual working memory, as argued by McConnell & Quinn (2003), or whether interference occurs as a result of interactions between perception, long term memory and visual working memory, as argued by Logie (2003).

In the current experiment we systematically manipulated both sequential/simultaneous modes of presentation and appearance/location during the presentation phase of visuo-spatial memory tasks. The data suggest that dissociations found in some previous studies between memory for location and memory for visual appearance, as reviewed in the introduction, need not be attributed solely to the use of sequential presentation for the former and simultaneous presentation for the latter. Furthermore, this study demonstrates that evidence for segregating the processing of appearance and location is robust against variations in mode of presentation. These conclusions add to the growing weight of evidence that there are separate subsystems within VSWM for supporting the retention of spatial location and of visual appearance.

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(Table 1)

Table of means for raw and percentage accuracy, broken down by memory condition, sequentiality and interference task.

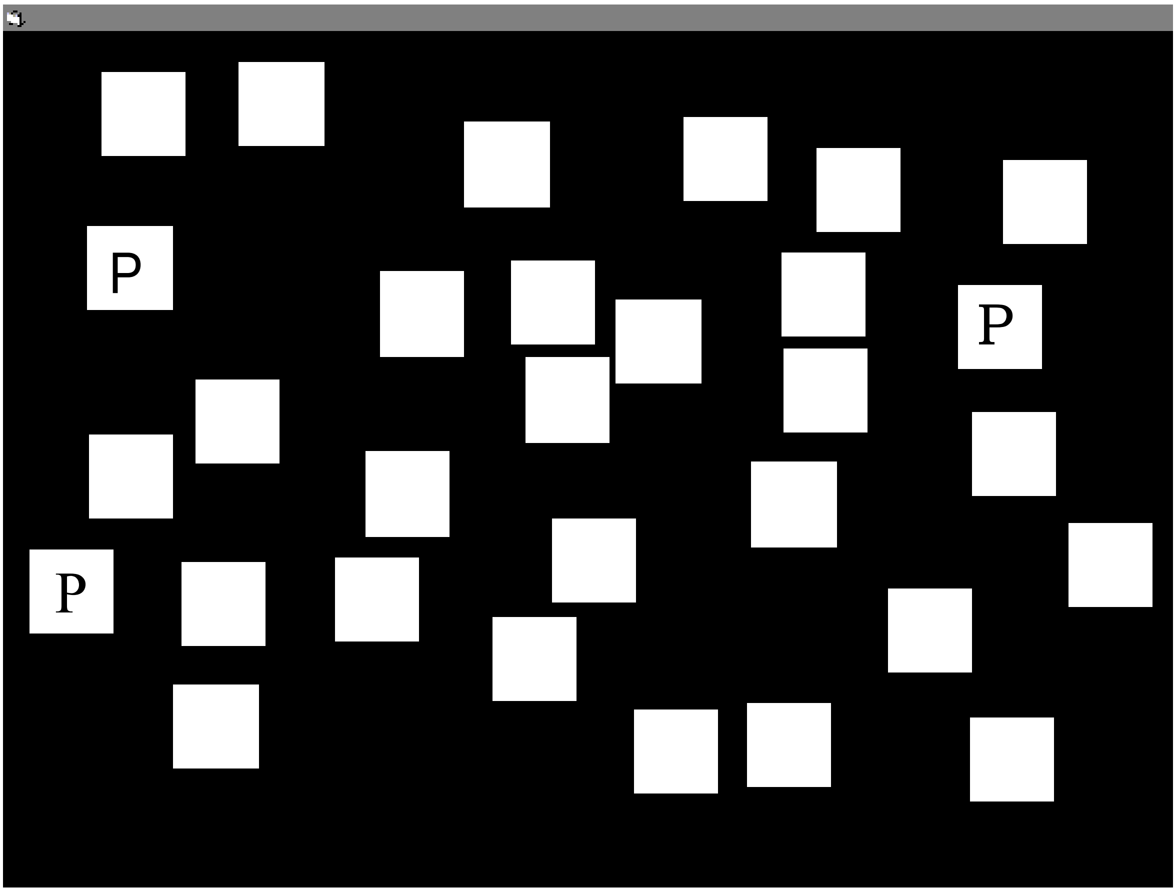
			Appearance				Location			
			Simultaneous		Sequential		Simultaneous		Sequential	
			Tapping	DVN	Tapping	DVN	Tapping	DVN	Tapping	DVN
Delay	Unfilled	(mean)	17.83	17.29	17.38	18.13	19.00	18.33	17.75	18.25
		(s.d.)	1.97	1.88	1.61	1.98	2.23	2.57	2.01	(1.96)
	Filled	(mean)	17.29	15.67	16.46	16.58	16.38	17.33	14.75	17.63
		(s.d.)	2.03	2.51	2.13	2.52	2.55	3.37	2.63	(2.1)
Percentage Accuracy Unfilled/filled x 100			97.61	91.22	95.72	92.12	86.53	94.97	82.97	97.32
			12.36	15.61	16.56	14.71	11.64	15.64	11.07	13.47

Figure Captions

(Figure 1) Screen Image of the Letter P Task, Showing 30 Randomly Positioned Squares, 3 of which Contain Letter Ps.

(Figure 2) Graph of 2-way interaction between memory condition and interference task for percentage accuracy scores ($F(1,184) = 16.41$, $p < .001$, MSE = 196.41, $\eta^2 = .08$) Clear bars – DVN interference, grey bars – tapping interference. Error bars represent standard errors of the means.

(Figure 1)



(Figure 2)