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Insensitivity of visual short-term memory to irrelevant visual information

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Short title: Interference with visual STM

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ABSTRACT

Several authors have hypothesised that visuo-spatial working memory is functionally analogous to verbal working memory. Irrelevant background speech impairs verbal short-term memory. We investigated whether irrelevant visual information has an analogous effect on visual short-term memory, using a dynamic visual noise (DVN) technique known to disrupt visual imagery (Quinn & McConnell, 1996a). Experiment 1 replicated the effect of DVN on pegword imagery. Experiments 2 and 3 showed no effect of DVN on recall of static matrix patterns, despite a significant effect of a concurrent spatial tapping task. Experiment 4 showed no effect of DVN on encoding or maintenance of arrays of matrix patterns, despite testing memory by a recognition procedure to encourage visual rather than spatial processing. Serial position curves showed a one-item recency effect typical of visual short-term memory. Experiment 5 showed no effect of DVN on short-term recognition of Chinese characters, despite effects of visual similarity and a concurrent colour memory task that confirmed visual processing of the characters. We conclude that irrelevant visual noise does not impair visual short-term memory. Visual working memory may not be functionally analogous to verbal working memory, and different cognitive processes may underlie visual short-term memory and visual imagery.

The model of working memory proposed by Baddeley and Hitch (1974; Baddeley, 1986) comprises three components. The phonological loop maintains verbal and acoustic information in a passive phonological store in which representations are refreshed by an articulatory rehearsal process. The visuo-spatial sketchpad maintains visual and spatial information by potentially analogous processes. The central executive, an attentional and co-ordinating system, uses the representations stored in these two ‘slave systems’ in complex cognitive tasks such as reasoning and comprehension. Evidence from brain imaging (Jonides, Smith, Koeppe, Awh, Minoshima, & Mintun, 1993), developmental studies (e.g., Hulme, Thomson, Muir, & Lawrence, 1984; Nicolson, 1981), and studies of individuals with brain damage (e.g., Baddeley, Papagno & Vallar, 1988; Hanley, Young & Pearson, 1991) supports this model but its development has probably been influenced most by laboratory studies of the effects of active and passive interference on short-term memory performance. In this paper we report five experiments which explore the effects of passive interference on visuo-spatial working memory.

Interference techniques have helped to characterise verbal working memory as an articulatory rehearsal process maintaining phonological representations in a passive store. Active interference techniques, where the subject is required to perform a secondary task concurrently with the memory task, have been used to address issues of rehearsal, and have shown that concurrent articulation interferes more with verbal short-term memory (e.g., Levy, 1971) than with visuo-spatial short-term memory (e.g., Kroll, Parks, Parkinson, Bieber, & Johnson, 1970; Smyth, Pearson & Pendleton, 1988) supporting the hypothesis that short-term memory is a function of modality-specific storage systems. Passive techniques, such as irrelevant background noise during stimulus presentation, have been used to investigate the nature of stored representations, via the premise that speech has obligatory and direct access to the phonological store. Colle and Welsh (1976) showed that hearing irrelevant German speech reduced Englishspeaking subjects' immediate serial recall of visually presented numbers, suggesting that the visually presented material was converted to a sub-lexical code. Salamé and Baddeley (1982) supported this, finding that spoken words containing the same phonemes as visually presented digits (*tun*, *woo*) interfered as much with digit span as spoken digits did. Recent research has used irrelevant speech to challenge this conclusion. For example, Jones and Macken (1995) showed that irrelevant rhyming words disrupted recall of visually presented letters less than did irrelevant dissimilar words. They argue that irrelevant speech disrupts serial recall by interfering with order information, rather than by interfering with item codes in the phonological store.

Interference techniques have also been employed to characterise visuo-spatial working memory, although research initially focused on whether the visuo-spatial sketchpad was essentially visual or spatial, rather than addressing the nature of the rehearsal and storage processes in visuo-spatial working memory. Baddeley and Lieberman (1980) argued that the visuo-spatial sketchpad was predominantly spatial because a concurrent spatial task (blindfolded tracking of a pendulum by means of auditory feedback) impaired performance on a visuo-spatial imagery task whereas a concurrent visual task (brightness judgements) had no effect. However, their data may reflect their choice of imagery task rather than the underlying nature of the visuo-spatial sketchpad. The imagery task, devised by Brooks (1967), required subjects to memorise a set of sentences (e.g., "In the starting square put a 1, in the next square to the right put a 2, in the next square down put a 3 …") by visualising a route through a matrix. Correct memory for the sequence of spatial locations is critical for accurate recall of the sentences, therefore this task may load particularly heavily on the spatial processes in a system that is both spatial and visual. In fact, Beech (1984) failed to replicate Baddeley and Lieberman's (1980) finding: in all three of his experiments, brightness judgements impaired performance on the spatial task as much as did concurrent spatial tapping tasks. Quinn (1988) obtained intermediate results, finding an effect of concurrent brightness judgements on Brooks' spatial matrix performance that was statistically significant but smaller than the effect of concurrent unseen arm movements to specified locations.

Studies using the Brooks' spatial matrix task suggested that visuo-spatial working memory is certainly spatial, and probably visual too. Research using tasks that are more distinctly visual or distinctly spatial, rather than involving both aspects, has given clearer results, suggesting that working memory relies upon separate visual and spatial processes. For example, Logie and Marchetti (1991) demonstrated a double dissociation between visual and spatial working memory. Spatial hand movements during a retention interval selectively interfered with memory for spatial locations whereas irrelevant pictures selectively interfered with memory for colour hues. Della Sala, Gray, Baddeley, Allamano and Wilson (1999) showed that viewing irrelevant pictures during a retention interval interfered more with memory for matrix patterns than with memory for Corsi Blocks sequences, whereas an unseen spatial tapping task interfered more with memory for the spatial sequences than with memory for the patterns. Similarly, Tresch, Sinnamon and Seamon (1993) asked subjects to remember the spatial location of a dot or the visual form of a geometric shape. During a 10s retention interval, subjects performed a movement-discrimination task which required detection of a stationary object in an array of slightly moving objects, or a colour discrimination task where they decided if a colour shade was more red than blue. The movement discrimination task selectively impaired recognition of the dot location whereas the colour discrimination task selectively impaired recognition of the geometric shape. Data from neuropsychological and developmental studies also suggest dissociable visual and spatial working memory processes (Della Sala et al., 1999; Levine, Warach & Farah, 1985; Logie & Pearson, 1997; Owen, Sahakian, Semple, Polkey & Robbins, 1995). A possible interpretation of this pattern of data is that there are separate visual and spatial systems in working memory, each with its own storage and maintenance mechanisms. However, an alternative interpretation has attracted more research interest. Logie (Logie, 1995; Baddeley & Logie, 1999) argued that the observed dissociations reflect the operation of a visuo-spatial working memory system which retains pictorial and location information by a combination of spatial and visual processes. He argued that spatio-motor processes (the "inner scribe") helped maintain or "rehearse" representations in a passive visual store (the "visual cache").

Logie's view of visuo-spatial working memory parallels Baddeley's (1986) account of articulatory rehearsal processes and phonological storage in verbal working memory, suggesting that the two slave systems have similar functional architectures. If this were so, it should be possible to design visuo-spatial tasks analogous to verbal working memory tasks, and to detect a parallel range of phenomena in the two systems. However, passive visual interference effects in visuo-spatial working memory have tended to be unreliable. Logie (1986) showed disruptive effects of irrelevant line drawings and matrix patterns on use of the pegword imagery mnemonic, but Quinn and McConnell (1996a) reported both difficulty replicating the result and data suggesting that line drawings tapped general attentional resources rather than loading purely on visuo-spatial working memory. An alternative visual interference task, namely brightness judgements, similarly gave conflicting results (Baddeley & Lieberman, 1980; Beech, 1984; Quinn, 1988).

Quinn and McConnell have described a visual interference technique, known as *dynamic visual noise* (DVN), which interferes more reliably and selectively with visual imagery. In its original form, the technique requires subjects to watch, but not attend to, an 80 x 80 display of small black and white squares. Random squares change colour from black to white or white to black at a rate of several hundred changes per second, creating a flickering effect. Quinn and McConnell (1996a) showed clear and selective effects of DVN on pegword imagery in three experiments. They replicated this result (1996b) and showed that DVN reduced verbal recall using the method of loci mnemonic. DVN does not interfere with verbal learning by rote rehearsal (Quinn & McConnell, 1996a, b, 1999), suggesting that it does not impose a general attentional load. Recently, Quinn and McConnell (1999; McConnell & Quinn, 2000) have shown that the amount of disruption caused by DVN varies with the number and rate of changes in the noise field, in a predictable and regular way.

Other researchers have replicated the selective effect of DVN on visual imagery. Smyth and Waller (1998) asked rock climbers to visualise previously seen climbing routes, either a vertical route where all the handholds were visible simultaneously during training or a horizontal route around a bulge in the wall that obscured some of the handholds from view. DVN selectively increased the time it took climbers to imagine climbing the vertical route, that is, the route where they were able to rely more on visual imagery because all the handholds could be seen at once when they were learning the route. Baddeley and Andrade (2000, experiment 6) asked subjects to imagine visual scenes, such as a game of tennis or a cat climbing a tree, and then to rate the vividness of their image. Images were rated as less vivid with concurrent DVN than with concurrent articulation or no interference.

Quinn and McConnell argue that DVN disrupts visual imagery by gaining obligatory access to the visuo-spatial sketchpad (1996a) or, more specifically, to a passive visual store in working memory (1999). In other words, DVN passively interferes with visual working memory in a way that is analogous to the interference effects of irrelevant speech in verbal working memory. If they are correct, DVN promises to be a valuable tool for investigating the nature of coding in visuo-spatial working memory, offering a way of selectively disrupting the storage component of the visuo-spatial sketchpad (i.e., the visual cache in Logie’s, 1995, model).

However, it remains to be demonstrated that DVN disrupts performance on visual working memory tasks other than those that involve imagery mnemonics. Whereas studies of irrelevant speech effects in verbal working memory used verbal memory span or serial recall tasks, DVN effects have only been reported in visual imagery rather than short-term memory tasks. Baddeley conceptualised the visuo-spatial sketchpad as “a temporary visuo-spatial store … that is capable of retaining and manipulating images” (1986, p. 143) and Logie, Zucco and Baddeley (1990) confirmed that visuo-spatial imagery and short-term memory tasks compete for modality-specific resources. However, subsequent research has questioned the assumption that identical processes underlie imagery and short-term memory (see Pearson, 2001, for discussion). For example, Morton and Morris (1995) reported a patient, MG, who showed a dissociation between normal spatial short-term memory (Corsi blocks) and impaired image transformation (e.g., mental rotation). It is therefore important to demonstrate effects of DVN on visual short-term memory before drawing general conclusions about interference with working memory.

The experiments reported in this paper addressed two theoretical issues by investigating the effects of DVN on visual short-term memory. First, is visual short-term memory similar to visual imagery in its susceptibility to DVN interference? Second, is visual working memory analogous to verbal working memory in its susceptibility to passive interference? If the visuo-spatial sketchpad is functionally analogous to the phonological loop, and given that irrelevant speech is thought to disrupt storage of verbal information (e.g.,. Salamé & Baddeley, 1982), we would expect DVN to interfere with maintenance rather than encoding of visual information. If we can demonstrate that DVN interferes selectively with maintenance of visual information, then it should prove a useful technique for selectively impairing storage in the passive visual cache, while leaving the spatio-motor rehearsal processes of the inner scribe unaffected.

We began by confirming that, in our laboratories, DVN selectively disrupted use of the pegword mnemonic. We then tested the effect of DVN on a range of visual short-term memory tasks, beginning with recall of matrix patterns (Experiments 2 and 3) and then introducing recognition procedures and new stimuli to ensure that subjects used visual working memory strategies (Experiments 4 and 5).

EXPERIMENT 1

Experiment 1 sought to replicate the finding (Quinn & McConnell, 1996a) that DVN selectively impairs visual imagery. Subjects were required to learn lists of words either via verbal rote rehearsal or by using the pegword imagery mnemonic while being presented with irrelevant visual material, namely concrete line drawings, abstract line drawings or DVN. Following Quinn and McConnell (1996a), we predicted that line drawings would have a general disruptive effect on learning whereas DVN would impair pegword imagery but not rote rehearsal.

Method

Subjects and Design

Thirty-six first-year students enrolled at the Faculty of Psychology and Educational Sciences, University of Ghent, participated for course requirements and credit. Interference condition (control, concrete line drawings, abstract line drawings, dynamic visual noise) was manipulated within groups. Memory instructions (pegword or rote rehearsal) were manipulated between groups, hence 18 subjects learned words by rote rehearsal in the four interference conditions and 18 learned words using the pegword imagery mnemonic in the four interference conditions. Subjects were randomly assigned to groups and the order of the interference conditions was counterbalanced within each group.

Materials

Word lists were constructed using a subset of two hundred high imageable, one-syllable Dutch words chosen from the 7-point scales of the van Loon-Vervoorn (1985) norms. The selected words had a mean imageability rating of 6.59 (range 6.10 to 6.93). The pegword mnemonic was a Dutch translation of the “one is a bun, two is a shoe…” mnemonic used by Quinn and McConnell (1996a). One hundred line drawings of common objects and animals chosen from the 7-point scales of the Martein (1995) norms served as irrelevant concrete material. The selected drawings had a mean rating of 5.37 (range 3.14 to 6.91) on the dimension of familiarity. One hundred abstract line drawings were created and rated for familiarity in a preliminary study. The mean ratings on a 7-point scale ranged from 1.08 to 2.42 ($M = 2.01$). The DVN display was adopted from Quinn and McConnell (1996a); their source code was translated by us into Borland C++ to run on an IBM compatible computer. The 80 x 80 array of randomly black and white squares measured 10.5 x 10.5 cm on a 14 inch NEC 2A monitor. The colour of the squares changed continuously between black and white at a rate of a random 291 changes per second.

Procedure

The procedure was essentially the same as that used by Quinn and McConnell (1996a). Subjects were tested individually in a quiet room. They were sitting approximately 50 cm from the computer screen. Half the subjects were instructed to learn the word lists via rote rehearsal; the other half were instructed to use the one-bun pegword mnemonic, which involved learning a series of ten pegwords (the Dutch equivalent of “one is a bun, two is a shoe”, etc.) and subsequently using this rhyme to learn the lists of words by generating an integrated visual image of the first word and a bun, the second word and a shoe, etc. Subjects were given a practice trial to ensure they were clear on the memory strategy they had to use. In all conditions, subjects received one practice list and four experimental lists. Under verbal processing instructions, subjects had to retain lists of seven words. In the visual mediation condition, the lists consisted of ten words. In the rote memory condition word presentation was one per 4 sec; in the imagery mnemonic condition it was one per 5 sec. Each word was preceded by a number to indicate its list position (rote instructions) or by the pegword in order of learning (visual mnemonic instructions). These were presented vocally. The list lengths and presentation times in the two learning conditions were the default parameters used by Quinn and McConnell (1996a, experiments 2 and 3).

At the end of each list followed a 10 sec interval after which subjects were instructed to recall. The to-be-remembered words were verbally cued with their number in the list (rote rehearsal) or with the pegword (visual imagery mnemonic) in order of presentation at a rate of one recall cue per 4 sec. Presentation of the word lists was aural and recall was spoken aloud.

Presentation of the irrelevant visual material was computerised. The concrete and abstract line drawings were presented to coincide with the presentation of the words. There was a 1 sec blank screen between each presentation. The latter coincided with the next pegword or number of the word in the list. The DVN remained constantly on the computer monitor. The presentation of the irrelevant material continued during the 10-sec delay and recall. Subjects were instructed to keep their eyes open and to focus on the center of the computer screen. They were informed that the stimuli on the screen were irrelevant to the word-learning task. In the control condition, subjects were told to look at the blank monitor.

Results

[table 1 about here.]

Table 1 shows the mean percentage recall scores in the different conditions. A comparison of the percentage of words correctly recalled by the rote rehearsal and pegword imagery groups in the control condition showed a marginally significant difference, F(1, 34) = 3.56, p = .06, suggesting that the two groups were not perfectly matched for performance. The effects of learning strategy and interference condition on the percentage of words correctly recalled were analysed by a 2 (memory instructions) X 4 (interference condition) mixed ANOVA. Recall scores overall were lower with pegword imagery than rote rehearsal, F(1, 34) = 7.88, p < .01. Nonetheless, the other results essentially replicated those of Quinn and McConnell (1996a). The effect of interference condition was highly significant, F(3, 32) = 25.06, p < .001, and there was a significant interaction between learning strategy and interference condition, F(3, 32) = 3.60, p < .05. Newman-Keuls comparisons of the individual interference conditions against the control condition for each memory instruction group showed that the concrete pictures interfered with both pegword imagery and rote rehearsal (p < .001 for each comparison). Abstract pictures also interfered with both types of learning, though did so more strongly with pegword imagery (p < .001) than rote rehearsal (p < .05). DVN interfered strongly with pegword imagery (p < .001) but had no significant effect on rote rehearsal (p > .10).

Discussion

These results corroborate Quinn and McConnell’s argument that DVN selectively disrupts visuo-spatial imagery processes whereas pictures impose a more general attentional load. However, there is an alternative interpretation of our results, if they are taken in isolation. Tasks which are generally more demanding of cognitive resources, because they require elaboration of the initial stimulus, may simply be more susceptible to interference that simpler tasks, even when performance on both types of task is matched. Thus pegword imagery may be generally more susceptible to interference than rote rehearsal. DVN had a numerically smaller effect on pegword imagery than concrete or abstract pictures, so perhaps it was a strong enough interference technique to affect performance on the demanding imagery task but not strong enough to affect the simpler rote rehearsal task. Quinn and McConnell (1996a, experiment 1) obtained a similar result, finding that DVN interfered slightly less with pegword imagery than did line drawings. However, they also demonstrated a cross-over interaction in which irrelevant speech interfered with rote rehearsal but not pegword imagery, and DVN interfered with pegword imagery but not rote rehearsal (1996a, experiment 3). This finding shows that rote rehearsal is not insensitive to all types of interference. It therefore strengthens Quinn and McConnell's conclusion that DVN interferes selectively with visuo-spatial processing. Taken in the context of Quinn and McConnell's research, our results confirm that DVN as used in our laboratory selectively impairs visual imagery.

EXPERIMENT 2

Experiment 2 assessed the effect of DVN on retention of static matrix patterns similar to those used to investigate adults' and children's visual short-term memory (Della Sala et al., 1999; Logie, Zucco & Baddeley, 1990; Phillips & Christie, 1977a,b; Wilson, Scott & Power, 1987). Similar patterns have also been used as visual stimuli in a study to demonstrate the separate developmental pathways of visual and spatial memory (Logie & Pearson, 1997). Although short-term memory for visual patterns may require some spatial rehearsal, Logie and Pearson's data suggest that performance is constrained mainly by the capacity of the passive visual store or visual cache. DVN should gain obligatory access to that store and thereby impair retention of the patterns. Although McConnell and Quinn (2000) report that a static noise display had no effect on visual imagery performance, Experiment 2 included a blank screen condition as an additional control.

Method

Subjects and Design

Twenty four undergraduate students in the Department of Psychology, University of Sheffield, took part as a course requirement or for an honorarium. Interference condition (blank screen, static display, DVN) during retention of matrix patterns was manipulated within-subjects. The order of the interference conditions was fully counterbalanced.

Materials

Twenty one patterns were created, each comprising nine black squares in a matrix of 5 x 5 one-centimetre squares printed on white card. The black squares were chosen randomly, avoiding obvious patterns. Three patterns were used as practice items and six were used in each of the three interference conditions. Subjects recorded their responses in a booklet of printed, blank matrices of the same dimensions as the test matrices.

The DVN display was adapted from Quinn and McConnell (1996a); their source code was translated by us into TrueBasic to run on Macintosh computers. A Macintosh 5200 was used in this experiment. The 80 x 80 array of randomly black and white squares measured 17 by 17 cm. The colour of the squares changed continuously between black and white at a rate of approximately 440 changes per second. The static display comprised the same 80 x 80 array of randomly black and white squares, but no colour changes occurred. We used a plain grey screen display in the blank screen condition. The computer presented the DVN, static or blank screen displays constantly throughout all trials of the relevant condition.

Procedure

Subjects were tested individually in a quiet room with lighting arranged to minimise reflection on the computer monitor screen. They were told that they would be given 4 sec to memorise a black and white pattern, followed by a 36 sec retention interval (see note), and that at the end of the retention interval they should record the filled squares by marking the blank matrix in the response booklet. They were asked to remember the patterns as a whole, rather than trying to rehearse the co-ordinates of the black squares, for example. The experimenter placed a matrix pattern flat on the table in front of the subject for 4 sec, then removed it from view. After a 36 sec retention interval, a stopwatch beep signalled that it was time for the subject to respond. Subjects attempted two practice trials like this, with no interference. On the third practice trial, they were asked to look up at the computer screen as soon as the matrix pattern was removed, and to keep looking at the screen until they heard the response signal. As before, they were asked to focus on the middle of the screen but otherwise ignore the display. The screen display during this practice trial was the same as would be used in the first block of experimental trials.

Subjects completed six trials in the first interference condition (blank screen, static noise display or DVN). On each trial, the experimenter presented a pattern for 4 sec and checked that the subject looked at the computer screen for the entire 36 sec retention interval. The remaining two interference conditions were identical, except that the screen display changed. Each was preceded by a practice trial using the appropriate screen display.

At the end of the test session, subjects were asked whether they used any particular strategy to remember the matrices, for example, did they say to themselves something like ‘T shape top left’ or did they visualise the whole pattern.

Results

Recall performance on each trial was scored as the number of correctly marked squares. Subjects occasionally marked more than nine squares, in which case the number of excess squares was subtracted from the number of correct squares to give the score for that trial. The trial scores were summed to give a total recall score for each subject in each condition, expressed as a proportion of the maximum possible score of 54. Subjects scored a mean of .73 (*SD* .16) in the blank screen condition, .70 (*SD* .13) in the static screen condition, and .72 (*SD* .14) in the DVN condition. One-way analysis of variance confirmed that there was no effect of interference condition on pattern recall, $F < 1$. Four subjects scored higher than .90 in at least one condition. Removing their data did not alter the outcome of the analysis ($F < 1$), suggesting that the null result is not simply due to ceiling performance. Two subjects said they used verbal rehearsal of locations or shapes to help remember the patterns. Removing their data did not alter the outcome of the analysis ($F = 1.05$).

Discussion

Retention of the visual matrix patterns over a 36 sec retention interval was not affected by concurrent DVN. We suggest three possible explanations: i) short-term retention of matrix patterns does not load visual working memory, perhaps because subjects recode the static pattern as a sequence of black and white spatial locations. Although Logie and Pearson (1997) used this task to test children’s visual memory, and Della Sala et al. (1999) used it to test adults’ visual memory, perhaps our particular adult subjects preferred a spatial strategy; ii) DVN does not interfere with visual working memory. This explanation challenges Quinn and McConnell’s interpretation of their own findings, namely that DVN disrupts use of the pegword mnemonic because it gains obligatory access to the passive visual store of working memory; iii) our long retention interval may have encouraged subjects to treat the task as a long-term memory task. This explanation raises the question of why performance on the task was reasonably good when one might expect massive interference from repeated presentations of very similar stimuli. Nonetheless, Experiment 3 aimed to rule out this explanation.

EXPERIMENT 3

Experiment 3 replicated Experiment 2 but reduced the retention interval from 36 sec to 4 sec, ensuring that we assessed short-term memory for the matrix patterns. We included a spatial tapping condition instead of the static matrix display condition, to check that performance on the memory task was sensitive to active interference. If subjects use visuo-spatial working memory to perform this task, recall should be sensitive to interference with either rehearsal or storage processes, in the same way that verbal short-term memory is sensitive to articulatory suppression and irrelevant speech. Logie (1995) hypothesised spatio-motor rehearsal processes (the ‘inner scribe’) and visual storage (the ‘visual cache’), therefore we used a spatial tapping task to disrupt rehearsal and DVN to disrupt storage. Finding an effect of spatial tapping would support our assumption that subjects were actively rehearsing the stimuli in visuo-spatial working memory and not relying on long-term memory.

Method

Eighteen volunteers aged 14 to 46 (mean age = 21 years) took part at the University of Sheffield and were paid an honorarium. None had taken part in the previous experiments. Three interference conditions, blank screen, DVN and spatial tapping, were manipulated within-subjects. For the spatial tapping task, subjects were asked to tap as quickly and accurately as they could between two 1cm diameter raised targets fixed 30 cm apart on a wooden board held out of sight on their lap. Subjects practised the tapping task until they felt confident they could tap reasonably quickly (at least once per second) without missing the targets or looking down at the board. They were instructed to look at the blank computer screen while tapping. The materials and procedure were otherwise identical to Experiment 2, except that the retention interval lasted 4 sec instead of 36 sec.

Results

Recall performance in each condition was scored as the total number of correctly marked squares minus any squares marked in excess of nine on any trial, expressed as a proportion of the maximum possible score of 54. Subjects scored a mean of .67 (*SD* .08) in the blank screen condition, .64 (*SD* .08) in the DVN condition, and .55 (*SD* .11) in the spatial tapping condition. One-way analysis of variance showed a significant effect of interference condition on recall, $F(2,34) = 9.32$, $p < .001$. Newman-Keuls comparisons showed a significant difference between the spatial tapping and blank screen conditions, $p < .01$, and between spatial tapping and DVN, $p < .01$, but no difference between the DVN and blank screen conditions. Self-reports suggested that eleven subjects used some verbal processing in addition to visuo-spatial processing. The mean recall scores of the seven subjects who reported no verbal processing were .62 in the blank screen condition, .64 in the DVN condition, and .49 in the tapping condition. In other words, only tapping interfered with their matrix memory.

Discussion

We replicated our previous finding that short-term retention of matrix patterns was unaffected by concurrent DVN. We also demonstrated a clear effect of spatial tapping on matrix memory, showing that we are not merely dealing with an exceptionally insensitive task or one in which subjects can avoid using visuo-spatial working memory. Although Logie (1995) hypothesised that visual and spatial processes act in concert in visuo-spatial working memory, one could explain our results by hypothesising separate visual and spatial working memory systems and assuming that subjects only used spatial working memory to retain the matrices. Although the matrix task was intended as a measure of visual short-term memory, it is possible that subjects used spatial strategies to remember the matrices, for example, rehearsing the locations of the filled squares. They may have been able to do this because each matrix contained only nine filled squares, or because they saw only one matrix on each trial. The recall test may also have encouraged spatial processing, because subjects necessarily marked the filled squares sequentially on the response grid. Thus we may have observed an effect of spatial tapping because it interfered with retention of spatial information (Tresch et al., 1993) rather than with spatial rehearsal of visual information as assumed in Logie's (1995) model. To encourage visual rather than spatial processing, subjects in the next experiment were shown four matrices per trial and were tested using a recognition procedure.

EXPERIMENT 4

This experiment used a visual recognition procedure based on the Phillips and Christie paradigm (1977a,b). On each trial, subjects saw a sequence of four square matrix patterns, presented individually. Each 5 x 5 matrix contained 13 filled squares. Memory was tested by asking subjects whether a probe pattern was identical to one of the patterns they had seen before. This procedure aimed to encourage visual processing by increasing the amount of material to be remembered (making it difficult to rehearse the specific locations of every filled square) and by using recognition rather than recall to test memory. Sequential presentation of the matrix patterns enabled us to test the effect of DVN during encoding (in the inter-stimulus intervals) as well as during the retention interval. Sequential presentation also allowed us to confirm the one item recency effect that is typical of visual short-term memory (Phillips & Christie, 1977 a,b).

Method

Subjects and Design

Sixteen first-year students at the Faculty of Psychology and Educational Sciences of the University of Ghent participated for course requirements and credit. The experiment used a 2 (interference condition: control versus DVN) x 2 (locus of interference: encoding versus maintenance) x 2 (probe: old versus new) design with repeated measures on the first and the last factor. All subjects took part in the matrix recognition task in both the control and visual interference conditions, the order of which was counterbalanced across subjects. Half the subjects received DVN during encoding, the other half during retention, with random allocation to each condition. On half the trials, selected at random, the probe was identical to one of the matrix patterns previously shown, i.e. old; in the other trials the probe pattern was new. For the old trials, each serial position of the probe was tested an equal number of times.

Materials

One hundred 5 x 5 square matrix patterns were constructed, each with 13 cells filled at random. Obvious patterns were avoided. The matrices measured 2 x 2 cm and were displayed on a 14 inch NEC 2A monitor connected to an IBM compatible computer. The DVN display was identical to that used by Quinn and McConnell (1996a). Their source code was translated into Borland C++ to run on the IBM compatible computer.

Procedure

Subjects were tested individually, seated approximately 50 cm from the computer screen. They were given instructions about the visual recognition procedure and attempted two practice trials.

On each trial four matrix patterns were presented one at a time in the middle of the screen. Each pattern was displayed for 1.5 sec with an inter-stimulus interval of 1.5 sec. After a 6 sec retention interval following the presentation of the fourth stimulus, a probe pattern appeared in the middle of the screen. Subjects were required to indicate whether the probe was identical to one of the previously presented stimuli or not, by pressing one of two keys. They were asked to respond quickly and accurately. Accuracy and reaction times were recorded.

There were 24 trials with old probes and 24 trials with new probes in both the control and the visual interference condition, giving a total of 96 trials per subject. For each condition, there were six old trials at each of the four serial positions.

In the interference conditions, DVN was presented either during the four 1.5 sec inter-stimulus intervals (encoding condition) or during the 6 sec retention interval (maintenance condition). For all conditions, subjects were instructed to keep their eyes open and focused on the centre of the computer screen throughout the experiment.

Results

The number of trials correctly answered was expressed as a proportion and subjected to a mixed 2 (condition) x 2 (locus of interference) x 2 (probe type) ANOVA. DVN did not interfere with recognition memory, $F < 1$, regardless of when it was presented (see table 2).

[Table 2 about here]

Performance was significantly poorer for old probes (*M* = 0.70, *SD* = 0.20) than for new ones (*M* = 0.85, *SD* = 0.14), *F*(1, 14) = 15.55, *p* < .01. A further oneway ANOVA of the old trial scores showed a significant effect of serial position, *F*(3,12) = 5.96, *p* < .01, with a pronounced recency effect confined to the matrix pattern presented last in the sequence.

Reaction times of the correct trials were entered into a similar repeated measures ANOVA. The only effect to reach significance was that of interference condition, *F*(1,14) = 10.92, *p* < .01. Subjects responded more quickly with DVN (*M* = 2080 ms, *SD* = 321 ms) than in the control condition (*M* = 2241 ms, *SD* = 289 ms). Additional analysis of the old trials confirmed the effect of serial position, *F*(3,12) = 5.62, *p* < .02. Figure 1 shows accuracy and response speed as a function of the serial position of the probe.

[Figure 1 about here]

Discussion

Experiment 4 tested recognition of sequences of matrix patterns, rather than recall of single matrices, to maximise demands on visual rather than spatial memory processes. Performance on the “old” trials revealed a serial position curve characteristic of visual short-term memory, i.e., a clear one-item recency effect but no primacy effect, supporting our assumption that recognition of pattern sequences is essentially a visual task. Despite this, we once again failed to find an interference effect of DVN on the accuracy of visual short-term memory performance. It is not clear why subjects responded more quickly on the memory test in the DVN conditions. Perhaps they felt that the task was harder and they should therefore respond faster, before they forgot, or perhaps they found it easier and could respond more quickly.

Experiment 5 sought to replicate the null effect of DVN on visual memory accuracy – and its apparently beneficial effect on response speed – by testing probed recognition of Chinese characters. The new stimulus material enabled us to vary visual similarity, with the aim of demonstrating a visual similarity effect (e.g., Frick, 1985; Hue & Ericsson, 1988; Walker, Hitch & Duroe, 1993) to confirm the visual nature of the task.

Based on Logie’s model of visuo-spatial working memory, Experiment 3 had used a concurrent spatial task to interfere actively with rehearsal of visual stimuli. However, if there are in fact separate visual and spatial working memory systems, each with its own rehearsal mechanisms and storage formats, then it may be more appropriate to use a visual task to disrupt rehearsal of visual stimuli. The next experiment therefore compared the effect of DVN with the effect of a concurrent colour memory task which should interfere actively with visual rehearsal as well as retention. Visual similarity effects and visual interference via the colour memory task would confirm that we are dealing with a visual working memory task. A further failure to find effects of DVN on this task would confirm that DVN does not disrupt visuo-spatial working memory. Alternative explanations must then be sought for its effects on visual imagery.

EXPERIMENT 5

Subjects in Experiment 5 were required to remember arrays of visually similar or dissimilar Chinese characters, memory being tested by a recognition probe. Interference condition (control, DVN, or concurrent colour memory) was manipulated between subjects, to avoid any changes in strategy with condition that may have obscured interference effects in the preceding experiments. For the concurrent colour memory task, subjects were shown a grey square at the start of a trial and then, at the end of the trial, were asked to select that shade of grey from a choice of four shades of grey. This interference task has been shown to disrupt short-term memory for visual material (Kemps & Reynvoet, 1999; see also Tresch et al., 1993).

Method

Subjects and Design

Forty-two first-year students at the Faculty of Psychology and Educational Sciences of the University of Ghent participated for course requirements and credit. Subjects were randomly assigned to the conditions of a 3 (interference: control, DVN and colour memory) x 2 (visual similarity: similar versus dissimilar) factorial design with repeated measures on the similarity factor.

Materials and Procedure

The experiment was run on an IBM compatible computer linked to a 14 inch NEC 2A monitor. Sixty-four Chinese characters, consisting of 16 subsets of four visually similar items, were used as stimuli. These were obtained in a preliminary study in which the visual similarity of 99 Chinese characters, selected from a Chinese book on poetry, was rated in a pair-wise comparison procedure. The similarity ratings were entered into a multidimensional scaling analysis. Sixteen subsets of four visually similar characters were obtained from a two-dimensional solution. An example of such a subset is shown in Figure 2. Sixteen dissimilar subsets were created by selecting at random one character from each of four different similar subsets, with the constraint that each of the 64 characters was used once. Thus each Chinese character was shown twice, once in a visually similar sequence and once in a dissimilar sequence. The characters measured approximately 3 x 3 cm and were presented as black figures on a white background. Stimuli and DVN were viewed from a distance of 50 cm.

[Figure 2 about here]

Subjects were tested individually in a quiet room. They were given instructions about the recognition task and (in the dual-task conditions) the secondary task, followed by five practice trials. There were 32 experimental trials, comprising 16 trials of visually similar stimuli and 16 trials of visually dissimilar stimuli. The trials were presented in random order.

Participants initiated a trial by pressing a key. A sequence of four stimuli appeared in a horizontal array 3.5 cm from the top of the screen. Adjacent stimuli were separated by 2.5 cm. The four stimuli were presented simultaneously for 4 sec. After a 10 sec retention interval, a probe stimulus appeared 7.5 cm below the centre of the array shown earlier. The probe was one of the four characters that had just been presented, and was selected at random. Subjects had to indicate which of the four stimuli was identical to the probe by pressing one of four keys: C, V, B, or N. They were told to respond quickly and accurately.

In the control condition, subjects looked at the blank computer screen during the interval between presentation and probe. In the DVN condition, subjects watched the display of flickering dots during the retention interval. In the colour memory condition, a 10.5 x 10.5 cm square in a particular shade of grey was shown during the retention interval and, following response to the probe stimulus, four smaller squares (4 x 4 cm) each in a different shade of grey were presented in the middle of the screen from left to right in descending order of darkness. The distance between two squares was 2 cm. One square was the same shade as the larger square shown before. Subjects had to identify the shade presented earlier, again by pressing keys C, V, B, or N. There were six shades of grey. However, to discourage subjects from using verbal codes for the various shades, only the four darkest or the four lightest were presented on any one trial. For all conditions, subjects were instructed to keep their eyes focused on the computer monitor throughout presentation of each trial.

Accuracy and response speed of the primary task and the colour memory task were recorded.

Results

[Table 3 about here]

The number of items correctly recognised was expressed as a proportion and entered into a mixed 3 (interference condition) x 2 (visual similarity) ANOVA. Table 3 shows the mean data in the six cells. The analysis revealed main effects of interference, $F(2,39) = 9.36$, $p < .001$, and visual similarity, $F(1,39) = 11.95$, $p < .01$, but no interaction between these two variables, $F < 1$. Newman-Keuls comparisons showed that the colour memory task significantly impaired performance compared to the control condition ($p < .01$) and DVN condition ($p < .001$), which did not differ from one another.

Reaction times of the correct trials were subjected to a similar analysis. Neither the main effects of interference, $F(2,39) = 1.98$, $p > .15$, nor visual similarity, $F(1,39) = 2.47$, $p > .10$, nor the interaction between the two factors, $F < 1$, were significant.

Analysis of performance on the colour memory task revealed a mean proportion of shades of grey correctly identified of 0.82 ($SD = 0.06$), and a mean response speed of 2043 ms ($SD = 636$ ms). These measures did not vary as a function of visual similarity ($.20 > p > .30$). A multiple regression analysis was performed with the accuracy and latency data of the secondary task as predictor variables, and the recognition scores obtained on the primary task as the criterion variable. The multiple regression coefficient was 0.48, $F(2,11) = 1.60$, $p > .20$. The regression coefficients of the two performance measures were not significantly different from zero ($p > .40$), demonstrating that performance on the colour memory task was not related to performance on the primary task.

Discussion

In line with previous studies (e.g., Frick, 1985; Hue & Ericsson, 1988; Walker et al., 1993), this experiment showed a visual similarity effect, confirming our assumption that subjects used visual short-term memory to remember the Chinese characters. Despite this evidence for visual processing, we once again failed to find an effect of DVN on short-term memory accuracy. DVN also had no effect on response times, precluding a speed-accuracy trade-off and suggesting that the apparently beneficial effect of DVN on response times in Experiment 4 may have been a spurious result. The lack of an effect of DVN contrasts with the clear effect of the concurrent colour memory task, which impaired memory performance compared with both the control and the DVN conditions.

The DVN and colour memory tasks differ in that DVN requires no active processing – subjects are explicitly instructed to ignore the display – whereas the colour memory task requires encoding, storage and subsequent retrieval of the presented shade of grey. Consideration of the interference effect of the colour memory task may shed light on the lack of effect of DVN. In the colour memory interference condition, subjects must store a recently-presented shade of grey at the same time as storing the Chinese characters in visual short-term memory. They may also rehearse the shade of grey, therefore the locus of the interference effect may be either in the passive visual store or in rehearsal processes. If the colour memory task interferes with visual memory by competing for storage capacity, this would suggest that visual working memory *is* sensitive to passive interference but that irrelevant visual material does not have the obligatory access to visual working memory that irrelevant speech has to verbal working memory. However, if the passive visual store were the locus of both the colour memory task effect and the visual similarity effect, one would expect the two effects to interact. The fact that they did not suggests that colour memory interfered with visual rehearsal processes rather than with the passive visual store. This failure to demonstrate passive interference with visual short-term memory, either with DVN or the colour memory task, suggests that visual working memory is not analogous to verbal working memory in its sensitivity to impairment of storage by irrelevant stimuli.

GENERAL DISCUSSION

Although we replicated the effect of DVN on the pegword mnemonic task in Experiment 1, we observed no effect of DVN on performance of a range of visual working memory tasks. In Experiments 2 and 3, DVN had no effect on maintenance of matrix patterns similar to those used by previous researchers specifically to measure visual working memory capacity. Memory for the matrix patterns was sensitive to interference by a spatial tapping task, suggesting that the null effect of DVN was not due to lack of power or general insensitivity of the memory task. Experiment 4 used sequential presentation of four matrices per trial, to reduce the opportunity for recoding the visual stimuli as sequences of locations, and a recognition procedure to reduce further the spatial and sequential processing requirements of the task. DVN again had no effect on visual short-term memory performance. Finally, Experiment 5 used a recognition procedure to test short-term memory for Chinese characters. Visually similar characters were recognised less well than dissimilar characters, confirming that subjects used visual representations in this task. A concurrent colour memory task interfered with memory for the characters but DVN again had no effect. We conclude that irrelevant visual material does not compete for storage capacity in the passive visual store of working memory, perhaps because it does not gain obligatory access to that store.

A recent paper by Zimmer and Speiser (in press) reports findings that support ours, in that irrelevant visual information (similar to Quinn and McConnell's DVN) during a retention interval did not interfere with memory for matrix patterns. However, some previous researchers have managed to demonstrate selective interference with visual short-term memory. Thus Tresch et al. (1993) found that a colour discrimination task interfered with retention of object shapes. Our fifth experiment replicated this finding, showing that a colour memory task during a retention interval impaired recognition of Chinese characters even though DVN had no effect. It appears that tasks requiring higher cognitive processing of visual material (for example, memory for or decisions about colour) disrupt visual short-term memory whereas tasks that only require perception of irrelevant visual material (watching the DVN display) do not. Contrary to this conclusion, Logie and Marchetti (1991) found that irrelevant line drawings presented during a retention interval disrupted memory for colour hues. Della Sala et al. (1999) found that pictures of abstract paintings selectively disrupted memory for matrix patterns. These results suggest an effect on visual short-term memory of perceiving irrelevant visual information that we were unable to replicate. Quinn and McConnell (1996a) argued that pictures load general attentional resources rather than specific visual working memory resources, an argument supported by the results of our Experiment 1. However, it is unclear why a general attentional load should have impaired memory for visual material but not spatial material. Logie and Marchetti (1991) and Della Sala et al.'s (1999) studies therefore remain the clearest demonstrations that mere perception of irrelevant visual material disrupts visual working memory.

It is conceivable that the meaningful nature of the line drawings used by Logie and Marchetti (1991) enabled them to gain access to the passive visual store, even though they were irrelevant to the task in hand. This explanation may also apply, though more tenuously, to the abstract pictures used by Della Sala et al. (1999). Subjects may be able to prevent DVN disrupting visual memory because it is unstructured and meaningless. Logie’s (1995) view of working memory as a “workspace” for manipulating long-term memory representations, rather than as a “gateway” into long-term memory, provides an alternative explanation. He argues that information can only access working memory via long-term memory, not directly via perception. Hence, a line drawing of a house may activate a representation of a house in long-term memory, and the activated representation would then occupy some of the capacity of working memory. DVN may be too unstructured to activate any long-term memory representations and therefore cannot disrupt visuo-spatial working memory.

Contrast between visual and verbal short-term memory

Our results reveal an interesting difference between visual and verbal working memory. Visual short-term memory appears insensitive to interference by perceived but unattended meaningless visual material such as DVN. In contrast, verbal short-term memory is impaired by irrelevant background speech, even when that speech is incomprehensible to subjects (Colle & Welsh, 1976). However, verbal short-term memory is not impaired by less structured irrelevant sounds, such as white noise (e.g., Salamé & Baddeley, 1987), suggesting that verbal working memory stores items at a phonological, rather than auditory or whole-word, level of representation. The lack of an effect of DVN on visual short-term memory suggests a comparable ‘object-level’ representational format in visual working memory.

Another explanation of the lack of effect of DVN comes from work by Jones and colleagues suggesting that irrelevant speech disrupts coding and retrieval of order information, rather than the storage of verbal representations (e.g., Jones, 1993; Jones, Farrand, Stuart and Morris, 1995; Jones & Macken, 1995). Perhaps DVN has no effect on visual short-term memory because visual short-term memory tasks typically require little or no retention of order information, and DVN itself is not intrinsically ordered or sequential in the way that irrelevant speech is.

A more speculative explanation is that during our lifetime we can learn to prevent irrelevant visual information entering the passive visual store, yet for some reason cannot learn to prevent irrelevant speech entering the phonological store. A recent finding by Staples, Ford and das Gupta (1999) tantalisingly supports this explanation. In contrast to our results with adults, they found that DVN selectively impaired children’s performance on a visual short-term memory task. Taking Logie’s “workspace” view of working memory, this finding could also be explained by assuming that activation of representations in long-term memory becomes more selective with age, children’s representations being more easily activated by non-specific stimuli.

Contrast between visual short-term memory and visual imagery

The lack of effect of DVN on visual short-term memory tasks contrasts with its robust effect on visual imagery tasks such as the pegword mnemonic (see Experiment 1), and suggests that different processes underlie visual imagery and memory. One interpretation of the data is that visual imagery tasks require active processing of visual representations in a store or “workspace” that is separate from the passive store used to retain stimuli in visual short-term memory tasks. Only the active store is susceptible to interference by irrelevant visual material. This interpretation is consistent with Pearson, Logie and Gilhooly’s (1999; see also Pearson, 2001) recent theoretical distinction between an active visual buffer that manipulates conscious visual representations, and a passive visual cache that temporarily (and unconsciously) stores visual representations. In a similar vein, Vecchi and Cornoldi (1999) have argued that working memory tasks can be classified according to their demands on active rather than passive processing, active processing being more susceptible to interference than passive processing.

An alternative, and currently purely speculative, interpretation of our data is that DVN reduces the subjective experience of visual imagery without interfering with storage of the image representation in working memory. This hypothesis is consistent with Baddeley and Andrade's (2000) finding that DVN reduces subjective ratings of the vividness of visual images. Vividness of imagery may play a causal role in performance of complex tasks like verbal learning using the pegword or other imagery mnemonics, but not because vividness is causally linked to memory (the papers on this issue generally report no link, or a negative link, between vividness and memory performance; e.g., Heuer, Fischman & Reisberg, 1986; Richardson, 1979). Rather, vividness may affect the strategies that subjects deploy when tackling complex tasks. If subjects generate an image but do not perceive that image to be sufficiently vivid, they may lack confidence to proceed to the next step in the task. They may continue to try and improve their first image when their cognitive resources would be better applied to generating images for subsequent stimuli. A similar explanation may suffice for Smyth and Waller's (1998) finding that DVN increased the time taken to image a climbing route. We predict that complex imagery tasks will be susceptible to DVN interference because lack of vividness causes subjects to adopt less effective strategies or to spend too long on components of the task that require imagery. DVN will also reduce the perceived vividness of the representations retained in simpler tasks such as the visual short-term memory tasks used in the present study, but the reduction in vividness will not be accompanied by poorer performance because i) the underlying representation is unaffected and ii) the task encourages or requires subjects to respond even when unsure.

Smyth (personal communication) suggests another explanation, namely that DVN interferes with retrieval from long-term memory rather than with storage in working memory. This explanation is consistent with the observed effects of DVN on pegword mnemonic tasks and in Smyth and Waller's (1998) route imagery task, both of which require generation of images from long-term memory. Interestingly, Baddeley and Andrade (2000, experiment 6) observed that DVN had a larger effect on vividness ratings for images generated from long-term memory than for images of recently presented patterns. They attributed this finding to the spatial nature of the recently presented stimuli, compared with the more visual nature of the images based on information in long-term memory, but it could be due to DVN interfering with recall of visual information from long-term memory. A recent fMRI study showed that vivid recollection of pictures reactivated visual sensory cortex (Wheeler, Petersen & Buckner, 2000). DVN may interfere with visual imagery and recall at this perceptual level rather than disrupting storage in working memory. Smyth's hypothesis may not conflict with our hypothesis that DVN reduces vividness of imagery. Tasks that require recall from long-term memory may be more susceptible to changes in perceived vividness of imagery if subjects use vividness strategically to decide when they have retrieved adequate information.

Conclusion

In contrast to verbal short-term memory, visual short-term memory seems not to be susceptible to passive interference from irrelevant, meaningless visual information. DVN may be too unstructured to disrupt visual storage (akin to auditory white noise) or the assumed analogy between visual and verbal working memory may be misleading. Further research is needed to discover the minimum level of visual structure required to disrupt visual short-term memory, whether the locus of any interference is in storage of item information or order information, and whether during childhood we learn to prevent irrelevant visual stimuli interfering with working memory.

We found no effect of DVN on visual short-term memory despite replicating well-documented evidence for its disruptive effect on visual imagery. We speculate either that visual short-term memory and imagery load different components of working memory, with only the imagery component being susceptible to passive visual interference, or that DVN impairs imagery performance because it alters subjective experience of images without disrupting storage of the underlying representation. Both interpretations are intriguing because they suggest that Quinn and McConnell’s DVN technique provides a tool for very selectively disrupting components of visual working memory. Either it allows us to interfere with image manipulation without disrupting storage of visual information in short-term memory, or, more intriguingly still, it allows us to interfere with conscious experience of visual representations without altering the representations themselves.

Note

The parameters for Experiment Two were chosen for comparison with those of an unpublished study of the effects of DVN on performance of the Brooks spatial matrix task. In that study, nine sentences were presented at a rate of one per 4 sec, and a 36 sec retention interval was used to match encoding and maintenance times. DVN had no effect on encoding or maintenance of the spatial material, nor did a more structured dynamic display.

Table 1. Percentage of words recalled correctly following rote rehearsal and pegword imagery in the four interference conditions of Experiment One (± standard deviations).

	Control	Concrete	Abstract	DVN
Rote rehearsal	81.66 (11.68)	69.27 (11.73)	76.99 (13.07)	78.52 (13.10)
Visual mnemonic	74.53 (10.30)	59.17 (14.01)	63.39 (13.34)	65.02 (12.52)

Table 2. Mean pattern recognition scores with or without visual interference at encoding or maintenance in Experiment 4 (± standard deviations)

Interference during…	Control	DVN
Encoding	0.73 (0.16)	0.76 (0.16)
Maintenance	0.80 (0.10)	0.80 (0.10)

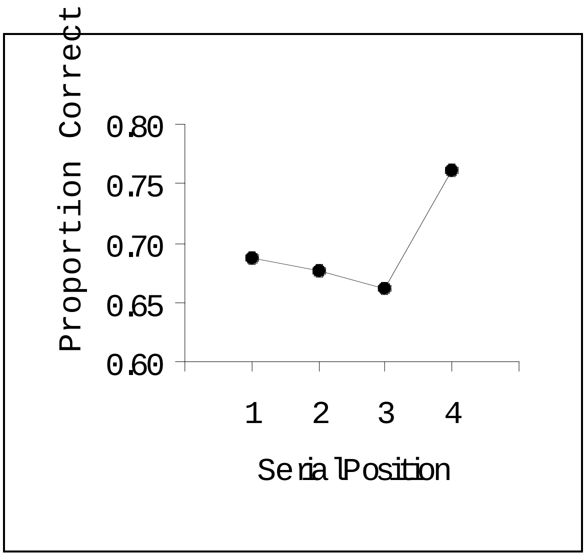
Table 3. Mean recognition scores for Chinese characters in Experiment 5 as a function of interference condition and visual similarity (± standard deviations)

Stimuli	Control	DVN	Colour Memory
Similar	0.66 (0.16)	0.71 (0.15)	0.54 (0.17)
Dissimilar	0.76 (0.16)	0.78 (0.15)	0.61 (0.19)

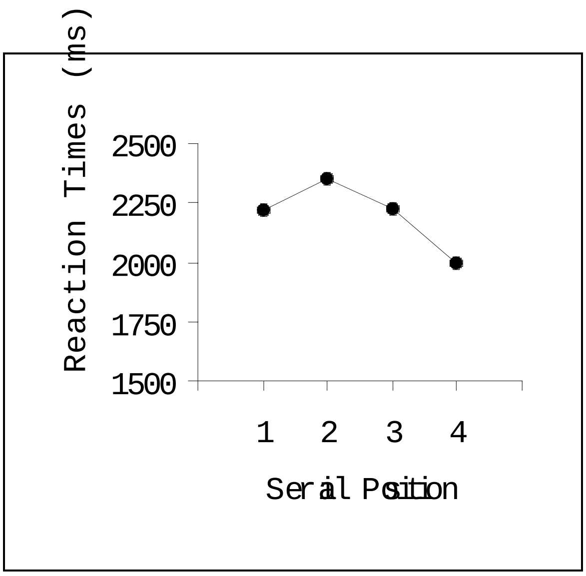
Figure captions

Figure 1. Serial position curves for the accuracy and latency of probe recognition on the old trials in Experiment 4.

Figure 2. Example of a subset of four visually similar characters used in Experiment 5.



ACCURACY



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REFERENCES

Baddeley, A. D. (1986). *Working Memory*. Oxford: Oxford University Press.

Baddeley, A. D. & Andrade, J. (2000). Working memory and the vividness of imagery *Journal of Experimental Psychology: General*, *129*(1), 126-145.

Baddeley, A. D. & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *Recent advances in learning and motivation, Vol. VIII,* pp. 47-90. New York: Academic Press.

Baddeley, A. D. & Lieberman, K. (1980). Spatial working memory. In R. Nickerson (Ed.), *Attention and Performance VIII,* pp. 521-539. Hillsdale, N.J.: Erlbaum.

Baddeley, A. D. & Logie, R. H. (1992). Auditory imagery and working memory. In D. Reisberg (Ed.), *Auditory Imagery*, pp. 179-197. Hillsdale, N.J.: Lawrence Erlbaum.

Baddeley, A. D. & Logie, R. H. (1999). Working memory: The multi-component model. In A. Miyake & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 28-61. Cambridge: Cambridge University Press.

Baddeley, A. D., Papagno, C. & Vallar, G. (1988). When long-term learning depends on short-term storage. *Journal of Memory and Language, 27*, 586-595.

Beech, J. R. (1984). The effects of visual and spatial interference on spatial working memory. *Journal of General Psychology, 110*, 141-149.

Brooks, L. R. (1967). The suppression of visualization by reading. *Quarterly Journal of Experimental Psychology, 19*, 289-299.

Colle, H. A. & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior, 15*, 17-31.

Della Sala S., Gray, C., Baddeley, A., Allamano, N. & Wilson, L. (1999). Pattern span: a tool for unwelding visuo-spatial memory, *Neuropsychologia, 37*, 1189-1199.

Frick, R.W. (1985). Testing visual short-term memory: Simultaneous versus sequential presentations. *Memory & Cognition, 13*, 346-356.

Hanley, J. R., Young, A. W., & Pearson, N. A. (1991). Impairment of the visuo-spatial sketch pad. *Quarterly Journal of Experimental Psychology, 43A*, 101-125.

Heuer, F., Fischman, D., & Reisberg, D. (1986). Why does vivid imagery hurt colour memory? *Canadian Journal of Psychology, 40,* 161-175.

Hue, C. & Ericsson, J. R. (1988). Short-term memory for Chinese characters and radicals. *Memory & Cognition, 16,* 196-205.

Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38,* 241-253.

Jones, D. M. (1993). Objects, streams and threads of auditory attention. In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness and control*, pp. 87-104. Oxford: Clarendon Press.

Jones, D., Farrand, P., Stuart, G., & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*, 1008-1018.

Jones, D. M., & Macken, W. J. (1995). Phonological similarity in the irrelevant speech effect: Within- or between-stream similarity? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 103-115.

Jonides, J., Smith, E. E., Koeppe, R. A., Awh, E., Minoshima, S., & Mintun, M. A. (1993). Spatial working memory in humans as revealed by PET. *Nature, 363,* 623-625.

Kemps, E. & Reynvoet, B. (1999). Visual confusions in working memory. In *Proceedings of the Seventh European Workshop on Imagery and Cognition*, J. T. E. Richardson (ed.), p. 34. Uxbridge: Brunel University.

Kroll, N. E., Parks, T., Parkinson, S. R., Bieber, S. L., & Johnson, A. L. (1970). Short-term memory while shadowing: Recall of visually and aurally presented letters. *Journal of Experimental Psychology, 85*, 220-224.

Levine, D. N., Warach, J., & Farah, M. J. (1985). Two visual systems in mental imagery: Dissociation of 'what' and 'where' in imagery disorders due to bilateral posterior cerebral lesions. *Neurology, 35,* 1010-1018.

Levy, B. A. (1971). The role of articulation in auditory and visual short-term memory. *Journal of Verbal Learning and Verbal Behavior, 10*, 123-132.

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: Lawrence Erlbaum.

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.

Logie, R. H. & Pearson, D. G. (1997). The inner eye and the inner scribe of visuo-spatial working memory: Evidence from developmental fractionation. *European Journal of Cognitive Psychology, 9*, 241-257.

Logie, R. H. Zucco, G. & Baddeley, A. D. (1990). Interference with visual short-term memory. *Acta Psychologica, 75,* 55-74.

Martein, R. (1995). Norms for name and concept agreement, familiarity, visual complexity and image agreement on a set of 216 pictures. *Psychologica Belgica, 35,* 205-225.

McConnell, J. & Quinn, J. G. (2000). Interference in visual working memory. *Quarterly Journal of Experimental Psychology, 53A,* 53-67.

Morton, N. & Morris, R. G. (1995). Image transformation dissociated from visuospatial working memory. *Cognitive Neuropsychology, 12,* 767-791.

Nicolson, R. (1981). The relationship between memory span and processing speed. In M. Friedman, J. P. Das, & N. O'Connor (Eds.), *Intelligence and Learnin*g, pp. 179-184. New York: Plenum Press.

Owen, A. M., Sahakian, B. J., Semple, J., Polkey, C. E., & Robbins, T. W. (1995). Visuo-spatial short-term recognition memory and learning after temporal lobe excisions, frontal lobe excisions or amygdalo-hippocampectomy in man. *Neuropsychologia, 33,* 1-24.

Pearson, D. G. (2001). Imagery and the visuo-spatial sketchpad. In J. Andrade (Ed.), *Working memory in perspective*, London: 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. M. (1977a). Components of visual memory. *Quarterly Journal of Experimental Psychology, 29,* 117-133.

Phillips, W. A. & Christie, D. F. M. (1977b). Interference with visualization. *Quarterly Journal of Experimental Psychology, 29*, 637-650.

Quinn, J. G. (1988). Interference effects in the visuo-spatial sketchpad. In M. Denis, J. Engelkamp & J. T. E. Richardson (Eds.), *Cognitive and neuropsychological approaches to mental imagery,* pp. 181-189. Amsterdam: Martinus Nijhoff.

Quinn, J. G. & McConnell, J. (1996a). Irrelevant pictures in visual working memory. *Quarterly Journal of Experimental Psychology, 49A*, 200-215.

Quinn, J. G. & McConnell, J. (1996b). Indications of the functional distinction between the components of visual working memory. *Psychologische Beitrage, 38*, 355-367.

Quinn, J. G. & McConnell, J. (1999). Manipulation of interference in the passive visual store. *European Journal of Cognitive Psychology, 11*, 373-390.

Richardson, J. T. E. (1979). Correlations between imagery and memory across stimuli and across subjects. *Bulletin of the Psychonomic Society*, *14*(5), 368-370.

Salamé, P. & Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior, 21*, 150-164.

Salamé, P. & Baddeley, A. D. (1987). Noise, unattended speech and short-term memory. *Ergonomics, 30,* 1185-1194.

Smyth, M. M., Pearson, N. A. & Pendleton, L. R. (1988). Movement and working memory - patterns and positions in space. *Quarterly Journal of Experimental Psychology, 40,* 497-514.

Smyth, M. M. & Waller, A. (1998). Movement imagery in rock climbing: Patterns of interference from visual, spatial and kinaesthetic secondary tasks. *Applied Cognitive Psychology, 12,* 145-157.

Staples, P. A., Ford, S. & das Gupta, M. (1999). Interference in children’s visual working memory. In J. T. E. Richardson (ed.), *Proceedings of the Seventh European Workshop on Imagery and Cognition,* p. 48. Uxbridge: Brunel University.

Tresch, M. C., Sinnamon, H. M. & Seamon, J. G. (1993). Double dissociation of spatial and object visual memory: Evidence from selective interference in intact human subjects. *Neuropsychologia, 31*, 211-219.

van Loon-Vervoorn, W.A. (1985). *Voorstelbaarheidswaarden van Nederlandse woorden.* Lisse, The Netherlands: Swets & Zeitlinger.

Vecchi, T. & Cornoldi, C. (1999). Passive storage and active manipulation in visuo-spatial working memory: Further evidence from the study of age differences. *European Journal of Cognitive Psychology, 11*, 391-406.

Walker, P., Hitch, G.J. & Duroe, S. (1993). The effect of visual similarity on short-term memory for spatial location: Implications for the capacity of visual short-term memory. *Acta Psychologica, 83*, 203-224.

Wheeler, M. E., Petersen, S. E. & Buckner, R. L. (2000). Memory's echo: Vivid remembering reactivates sensory-specific cortex. *Proceedings of the National Academy of Sciences USA, 97*, 11125-11129.

Wilson, J. T. L., Scott, J. H., & Power, K. G. (1987). Developmental differences in the span of visual memory for pattern. *British Journal of Developmental Psychology, 5,* 249-255.

Zimmer, H. D. & Speiser, H. R. (in press). The irrelevant picture effect in visuo-spatial working-memory: Fact or fiction? Psychologische Beiträge