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INTERFERENCE WITH VISUALIZATION

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It is often claimed that visualizing and perceiving interfere with each other because they compete for special purpose visual processing resources. The arguments for this view (e.g. Brooks, 1967, 1968) are criticised. Five experiments are then reported which attempt to determine whether specific processing activities interfere with the visualization of novel abstract patterns. Visualization was greatly interfered with by adding five digits but not by reading them. Presentation modality of the digits did not affect the interference they caused. When the intervening activity involved processing patterns similar to those being visualized, the amount of interference depended upon whether the subject had to form and use representations that outlived the icon. Perception caused interference when it involved formation of a maintainable representation, but not when it required only sensory storage.

It is concluded that visualization requires general purpose resources, and that interference between visualization and perception could be due to competition for these resources.

Introduction

It is widely claimed that visual imagery and visual perception interfere with each other because they compete for limited special purpose resources. The basic evidence for this view comes from Brooks' studies of the relative amount of interference between different pairs of tasks. Briefly, he showed that a task requiring visual imagery could be performed more easily while speaking than while pointing, whereas a verbal task could be performed more easily while pointing than while speaking (Brooks, 1968). He also showed that visualizing was easier while listening than while reading, whereas it was again the other way round for a verbal task (Brooks, 1967). The interpretation he suggested for these results has been accepted by many writers (e.g. Neisser, 1970; Norman, 1976; Baddeley, 1976) and is well expressed by Bower (1970):

> If remembering in visual imagery utilizes somewhat the same central mechanisms as are used in visual perception, competition for this limited capacity will result when the person must both visually guide his hand (to indicate answers to various questions about the memorized diagram) and simultaneously remember the spatial diagram in visual imagery. The general idea, therefore, is that two activities in the same modality will compete for a limited analyzer or processing capacity, whereas two activities in different modalities will tend to be less competitive, less disruptive and less interfering.

Similar results have been obtained using other tasks, and have usually been interpreted as evidence for modality specific visual interference.

The empirical demonstrations are impressive and the interpretation not implausible. The arguments for this interpretation, however, seem to us to be less conclusive than is usually supposed. To begin with, consider the finding that visualizing is interfered with more by pointing than by speaking. As Brooks noted, this finding by itself implies nothing about interference specificity because pointing may in general cause more interference than speaking. If it were the case that verbalization did not interfere at all with visualization, then it would seem reasonable to conclude that they use separate resources. Discussion of Brooks' results frequently assume that this is what they show, but, in fact, they provide no evidence on this matter, because they do not include "blank" conditions with which the effects of speaking can be compared. Experiments that do allow such a comparison clearly show that verbalization can interfere with visualization (e.g. Kelly and Martin, 1974; Yuille and Ternes, 1975). Specificity of processing, therefore, cannot be claimed upon the grounds of complete independence between the tasks.

The strongest claims for a special purpose visual processor were, therefore, based not upon the grounds that visualizing was interfered with more by pointing than by speaking but upon the grounds that this relative order of interference was reversed when a verbal task was being performed. We agree that this reversal implies interference specificity, but not that it implies visual interference specificity. There are two possibilities: either interference occurs between pointing and visualizing that does not occur between pointing and verbalizing: or interference occurs between speaking and verbalizing that does not occur between speaking and visualizing. The reversal in relative amounts of interference implies that one or the other of these is the case: it does not imply both.

In short, it has been assumed that the reversal in the relative amounts of interference shows specifically "visual" interference, whereas it could be due to specifically "verbal" interference. This ambiguity seems to apply to all claims for specific visual processors based upon such evidence, and the latter possibility must be taken seriously in view of the evidence that STM includes a specifically auditory or articulatory buffer (Baddeley and Hitch, 1974).

The question as to whether there are separate mental mechanisms for thinking in words and pictures is sometimes approached by treating it as identical to the question as to whether words and pictures have separate forms of representation. This approach is attractive because there is a very large body of evidence for this latter distinction. The identification of the two issues, however, seems quite invalid. A single processor can operate upon different forms of representation, and many processors can operate upon one form of representation.

Perhaps the most important problem in attempting to understand interference with visualization is that of analysing the complex intervening tasks to determine precisely which aspects are responsible for the interference caused. Describing one such aspect as "visual" is not very informative, requires empirical support, and may even be misleading (Baddeley, Grant, Wight and Thomson, 1975). As recent research has been primarily concerned with the modality in which the intervening task is performed, there has been less concern with the details of the task itself. This neglect is unfortunate because the kind of task performed may be at least as crucial to the interference caused as the modality within which it is performed. This neglect is also unfortunate because we may find out about the internal processes for which visualization is in competition by determining more precisely which aspects of the interfering tasks are relevant. The following experiments, therefore, examine changes in the task as well as changes in the modality within which it is performed. When changing the task within a modality an attempt was made to keep the task very similar except for a small alteration which should on good theoretical grounds change just a few of the internal processes involved. In this way we hoped to determine whether those particular processes are involved in the interference caused.

Previous experiments (Phillips and Christie, 1977) have shown that both a digit adding task and a pattern comparison task interfere with the visualization of novel abstract patterns. Both of these tasks are complex, however, and there was no evidence as to which of their components caused the interference. The following experiments are designed to provide further information on this problem by attempting to determine which specific aspects are responsible for the interference. "Blank" conditions are included so that evidence can be obtained as to whether interference is occurring or not, and the basic approach is to compare the interference caused by tasks differing only in the aspect under consideration. The following experiments study only a few specific aspects, but eventually a coherent picture might emerge showing which mental activities compete with visualization for resources and which do not.

General methods

The experiments were conducted on-line to a D.E.C. PDP 11/45 computer and the visual stimuli were presented on a Decgraphic 11 GT40 graphical display unit. Block patterns were formed by lighting randomly selected cells in a square matrix (usually 4×4). The probability of any cell being lit was 0·5 and new patterns were generated on each trial. A typical pattern subtended a visual angle of approximately 2° at a viewing distance of about 60 cm.

In these experiments same/different recognition performance was measured On each trial a pattern or a string of patterns was presented and then tested after a short retention interval (never more than 4 s) during which the interfering task was performed. When each pattern was presented for test it was either identical, or different by virtue of having one cell more, or one cell less, filled. The subject's task was to decide whether or not each test pattern was exactly the same as the corresponding pattern presented on that trial, and to press one of the console keys accordingly. As all patterns in the sequence were quite different, this was equivalent to deciding whether the test pattern had been previously presented at all. Responses "same" were made with the index finger of the right hand, responses "different" with the index finger of the left hand. Each test pattern was displayed until a response was made. At the beginning of each trial a flashing fixation point appeared on the screen and, when ready, the subject triggered the onset of the display sequence by pressing either of the two response keys.

"Same" and "different" conditions occurred at random and with equal probability. On trials in which a test pattern was different the cell to be changed was randomly selected. A record was made of the conditions pertaining for each trial along with the subject's response and his reaction time as measured from the onset of the test pattern.

The subjects were students and staff of the University of Stirling.

Previous experiments have developed methods for separating the visualization of a novel stimulus from the long-term memory for it (Phillips and Baddeley, 1971; Phillips and

Christie, 1977). These experiments suggest that, when a single pattern is used, visualization is reflected by that component of performance which decays or is susceptible to interference, and that, when a string of patterns is used, it is reflected by higher performance on the final pattern. Both procedures are used in the following experiments. Strings are used when evidence is needed as to whether interference is partial or complete.

The interference caused by digit tasks

The first two experiments study the effects caused by specific components of the digit processing task. In our previous experiments adding five visually presented digits entirely removed visualization. If visualization is carried out by a special purpose processor that is also used for visual recognition, then interference should depend upon the modality in which the digits are presented. If visualization is not dependent upon general purpose resources, the amount of interference should not depend upon whether the digits have to be added because it seems unlikely that adding is a specifically visual operation. Although it is very unlikely that visualization is entirely independent of general purpose resources, it is difficult to predict the exact extent to which adding the digits will increase the interference they cause.

Experiment I

Method

In each trial three patterns were presented sequentially and tested, after a retention interval of 4 s, in reverse serial order (last pattern tested first, first pattern tested last). A discussion of this method of testing may be found in Phillips and Christie (1977). The patterns were each presented for 750 ms and they were separated by an ISI of 250 ms. Each test pattern was displayed until a response was made, which, in turn, triggered the presentation of the next test pattern. Three responses were made per trial.

There were four experimental conditions which differed in the type of activity to be performed during the retention interval. In two conditions strings of 5 single digits were presented visually at the fixation point at a rate of 2 per s. The digits were clearly visible but small in relation to the size of the patterns. After the fifth digit there was a blank interval of 1·25 s before the onset of the test sequence.

In the first condition the subject was instructed to read the digits aloud. In the second condition his task was to add the digits together and to state their sum before the onset of the test sequence. The third condition was the same as the second except that the digits were presented auditorily via headphones. This was achieved by diverting the digit output to a second display console from which the experimenter read out the digits to the subject. In the fourth condition there was a blank retention interval of 4 s with no interpolated task.

Eight subjects each performed a block of 32 trials in each of the four conditions. The order in which the blocks were administered was balanced across subjects by means of a Latin Square design. Before each block, subjects were given between 8 and 16 practice trials. Testing was carried out in a single session lasting about 60 min for which each subject was paid £1.00.

Results

The number of correct responses was subjected to a two-way analysis of variance (3 serial positions $\times$ 4 interference conditions) with repeated measures. Both

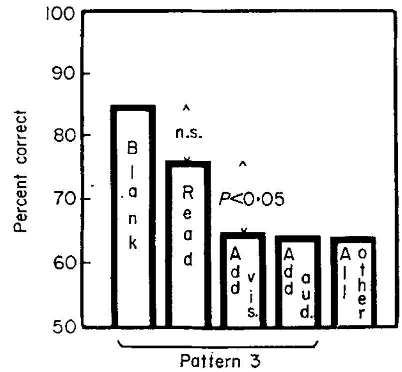

FIGURE 1. Experiment I. The effect of *overt* digit tasks on recognition of a string of patterns. Results for the final pattern for each of the four conditions are given separately. Results for all other patterns and conditions are combined, and are assumed to show LTM performance; i.e. performance without visualization.

the effects of serial position, $F(2,14) = 5{\cdot}59$, $P < 0{\cdot}05$, and of type of interference, $F(3,21) = 7{\cdot}67$, $P < 0{\cdot}005$, were significant. Their interaction was also significant, $F(6,42) = 3{\cdot}30$, $P < 0{\cdot}01$.

A post-hoc comparison (Scheffé test) indicated that there was no significant difference between positions 1 and 2 and that the significant serial position effect was due to the overall advantage of the final pattern. The significant interaction was largely due to the fact that the type of interference had its effect mainly on the final pattern.

The percentages of correct response over all subjects for the four conditions of interference for the final pattern and the mean of all other positions and conditions are shown in Figure 1 ("pure" chance performance in this and the following experiments is 50%). The scores for the final pattern were subjected to a separate one-way analysis of variance which yielded a significant effect of type of interference, $F(3,21) = 8{\cdot}34$, $P < 0{\cdot}001$. By means of a Newman-Keuls test ($\alpha = 0{\cdot}05$) it was found that the blank condition differed significantly from the two adding conditions but not from the reading condition. There was a significant difference between the effects of reading and adding visual digits, but there was no significant difference between adding visual digits and adding auditory digits.

There was no evidence for modality specific interference in this experiment. With both visual and auditory presentation, the task of adding digits had a powerful interfering effect on visualization, and indeed seems to remove it entirely, because in both adding conditions the final pattern is remembered no better than the first two. Reading digits, however, caused little or no interference.

The complete removal of visualization by adding leads to a difficulty in assessing the effect of modality. It could be argued that a floor effect may have militated against the appearance of any modality effect in the adding conditions. Floor effects are, therefore, avoided in the following experiment.

Experiment II

The intervening activity used in the previous experiment involved response selection, execution and monitoring in addition to the recognition and adding of digits, and these processes may have been largely or even entirely responsible for the interference. In Experiment II the same digit processing tasks were used, except that subjects were told to perform them without any overt responding. This also allowed inclusion of an auditory digit recognition condition for comparison with the read condition. (Pilot experiments indicated that overt shadowing produces *more* interference than overt reading, probably because shadowing produces output that conflicts with input.)

Method

On each trial a single pattern was presented for 1 s. Between the presentation of each pattern and its test there was a retention interval of 4 s during which a string of five digits was presented either visually or auditorily (except in the "blank" condition in which no stimuli were presented). Subjects were instructed to add or simply recognize the digits but without making any overt response. In addition to the four "interference" conditions of the previous experiment a fifth was included in which the subject was instructed simply to listen to the digits presented over the headphones.

Five paid subjects each performed a block of 40 trials in each of the five conditions which were administered during a single session of 1 h in an order balanced by means of a Latin Square design.

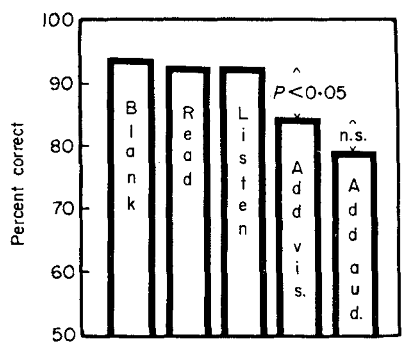

FIGURE 2. Experiment II. The effect of *covert* digit tasks on recognition of a single pattern.

Results and discussion

On debriefing, all subjects claimed to have performed the intervening tasks required. The percentage of correct response in each condition over all subjects is shown in Figure 2. A one-way analysis of variance with repeated measures, performed on the number of correct responses in the five conditions, yielded a significant effect of type of interference, $F(4,16) = 10{\cdot}37$, $P < 0{\cdot}001$. A Newman-Keuls test ($\alpha = 0{\cdot}05$) indicated that there was no significant difference among the "blank", "read" and "listen" conditions. The difference between each of the adding conditions and the other three conditions was significant, but the difference between the auditory and visual adding conditions was not significant.

A separate two-way analysis of variance (2 task × 2 modality), excluding the scores for the blank condition, confirmed the significant effect of task (recognize vs. add), $F(1,4) = 44 \cdot 56$, $P < 0 \cdot 005$, and the lack of a modality effect, $F(1,4) = 1 \cdot 37$, $P > 0 \cdot 25$.

These two experiments show that a short period of activity which is *prima facie* non-visual can disrupt or remove visualization. It appears that visual character recognition (reading digits) has little or no effect on visualization of this type of abstract pattern. If covert digit reading has any effect it is small and comparable to that caused by covert listening to digits.

The interference caused by visual pattern processing

So far we have produced no evidence that visual processing interferes with the visualization of novel patterns. Such interference is clearly indicated, however, by the large recency effect for the final pattern of a series (Phillips and Christie, 1977). This indicates that processing of the final item removes visualization of the previous items. In the experiments which follow, the basic approach is to consider the processing of the final pattern of a string as the source of interference with the previous item. The conditions pertaining for this pattern are manipulated and the effects on recognition of the next-to-last pattern are examined.

Theories of special purpose visual processors, such as Bower's (1971), are not well enough developed to make strong predictions as to the kinds of visual processing that will interfere with visualization. They seem to suggest, however, that interference will be caused by any task involving attention to, and processing of, visual input. An alternative prediction is that visual processing will cause interference only when it involves the use of schematic visual representations (Phillips, 1974).

Experiment III

Method

The sequence of events in each of the four conditions of this experiment are outlined in Figure 3(a). In all conditions the interval between presentation of pattern 2 and its test was 3·5 s. In the first condition, this interval was blank (i.e. no interfering pattern was presented). In the second condition, the third pattern acted as a suffix—it was always presented but never tested. In the third condition, pattern 3, the interfering pattern was tested after a delay of 50 ms in which case the experience tends to be that of seeing the change happen when the test pattern is different (Phillips, 1974). The fourth condition differed from the third only in that there was a delay of 750 ms between the presentation and test of the interfering pattern. A delay of this order requires construction of a schematic visual representation (i.e. of a representation that outlives the icon).

Eight subjects each performed a block of 32 trials in each of the four conditions. The order in which the conditions were administered was balanced across subjects by means of a Latin Square design. The subjects were Psychology undergraduates, and participation in the 1 h session, which included between 8 and 16 practice trials per condition, fulfilled a course requirement.

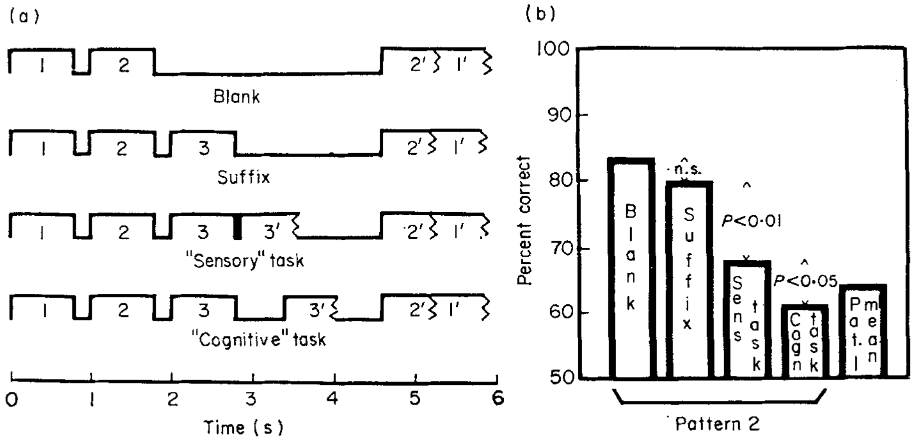

FIGURE 3. Experiment III. The effect of visual processing tasks on recognition of matrix patterns. (a) Method. 1′ etc. represents the test of pattern 1, etc. (b) Percentage of correct response as a function of type of interfering task. The mean score for pattern 1 is for all conditions combined, and is assumed to show LTM performance; i.e. performance without visualization.

Results

A two-way (2 serial positions × 4 interference conditions) analysis of variance with repeated measures was performed on the number of correct responses for patterns 1 and 2. There was a significant overall effect of serial position, $F(1,7) = 17{\cdot}13$, $P < 0{\cdot}005$, a significant effect of type of interference, $F(3,21) = 11{\cdot}33$, $P < 0{\cdot}001$, and also a significant interaction, $F(3,21) = 10{\cdot}44$, $P < 0{\cdot}001$.

An analysis of the scores for patterns in position 1 showed no significant effect of type of interference, $F < 1$. The scores for position 2 were subjected to a separate one-way analysis of variance so that detailed comparisons among the interference conditions could be carried out. The effect of type of interference at position 2 was highly significant, $F(3,21) = 30{\cdot}90$, $P < 0{\cdot}001$. Figure 3(b) above shows the percentage of correct response to pattern 2 as a function of type of interference. Comparisons among the conditions by Newman Keuls test ($\alpha = 0{\cdot}05$) showed the difference between the sensory and cognitive conditions to be significant, as was the difference between the suffix and sensory conditions. The blank and suffix conditions did not differ significantly.

Thus the presentation of a redundant pattern (suffix condition) did not significantly interfere with performance on pattern 2 as compared with performance when the retention interval was blank. Compared with these two conditions the sensory task caused significant interference, but it interfered significantly less than the cognitive task which reduced performance on pattern 2 to that on pattern 1 (i.e. to a level attributable to long term memory).

The interference caused by the sensory task could have been due to the visual processing, or to the demands of selecting and making a response. However, it could also be due to subjects unnecessarily forming a "cognitive" representation of the interfering pattern in the sensory task. The next experiment is, therefore, similar to Experiment III, but with changes intended to discourage subjects from forming a "cognitive" representation of the interfering pattern in the sensory task. As the difference in interference between the sensory and cognitive tasks, although significant, was small, it was felt that a further experiment was necessary to confirm the effect.

Experiment IV

Method

In this experiment only two patterns were used, because it was assumed, on the basis of Experiment III, that performance on the "cognitive" task would show the LTM level. The three conditions are illustrated in Fig. 4 (a). The blank condition of the previous experiment was omitted. In each trial a single 5×5 block pattern was followed by an interfering pattern which, instead of being of the same type as pattern 1, was in the form of an array of smaller separated cells. There are two reasons why this should reduce the tendency to form cognitive representations unnecessarily in the sensory task. The first is that as patterns 1 and 2 are now from different and easily distinguished sets of patterns it may be easier to switch off the process for generating cognitive representations when pattern 2 appears. The second is that it is, in any case, more difficult to form cognitive representations of separated dot patterns. These "dot" patterns were generated at random in the same way as the block patterns except that each cell was exactly half of the normal cell size and the cells were separated by a gap also equal to half of the normal cell size. The complete dot pattern was approximately the same size as a block pattern. The retention interval between presentation and test of the dot pattern was reduced to 20 ms in the sensory condition.

Six well-practised subjects each performed 64 trials in each of the three conditions which were administered in an order balanced across subjects.

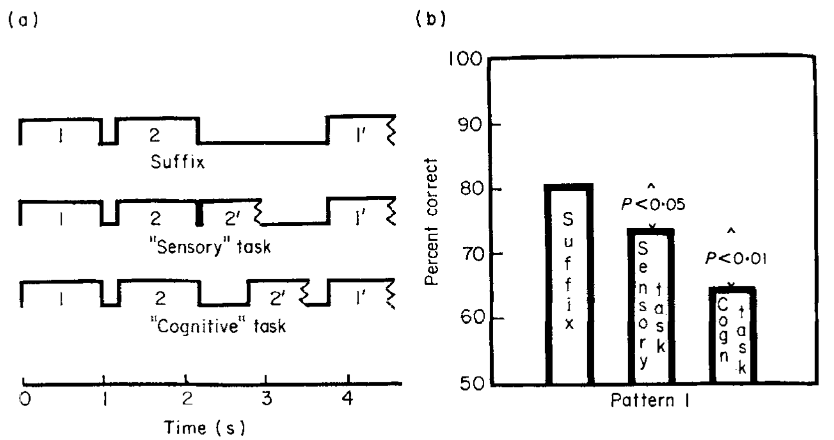

FIGURE 4. Experiment IV. The effect of processing a "dot" pattern (pattern 2) on the recognition of a "block" pattern (pattern 1). (a) Method. 1′ etc. represents the test of pattern 1, etc. (b) Percentage of correct response to pattern 1 as a function of type of processing of pattern 2.

Results and discussion

The percentages of correct response are shown in Figure 4(b) as a function of type of interference. A one-way analysis of variance performed on the number of correct responses showed the effect of type of interference to be highly significant, $F\ (2,10) = 15{\cdot}95$, $P < 0{\cdot}001$. The planned comparison (Scheffé method) of the sensory and cognitive conditions was significant, $F\ (1,10) = 10{\cdot}48$, $P < 0{\cdot}01$. A significant difference was also found between the suffix and sensory conditions, $F\ (1,10) = 5{\cdot}67$, $P < 0{\cdot}05$. Basically, similar results were obtained to those of the previous experiment. The procedural changes designed to discourage the formation of a schematic representation in the sensory condition increased the absolute difference between the sensory and cognitive conditions but the sensory task still caused significant interference. Experiment V looks more directly at the effects of requiring formation of a cognitive representation.

Experiments III and IV both show that comparison of two patterns causes more interference when they are separated by a 750 ms gap than when they are separated by a 20 ms or 50 ms gap. As these two conditions are identical in all other respects this is strong evidence that interference with visualization depends, at least in part, upon that processing of visual input which requires the use of representations that outlive the icon. The results also imply that the sensory task as a whole only partially interferes with visualization.

Experiment V

The tasks shown to produce interference in Experiments III and IV involve many different stages of processing. Any or all of these could be responsible for the interference. The final experiment asks whether the perceptual stage by itself causes interference. This is done by using a probe technique in which two patterns are presented, and one only is tested. The question is whether visualization of pattern 1 will be interfered with if it is tested immediately after the initial presentation of pattern 2. It is hypothesized that perception of pattern 2 will interfere only when the subject is trying to construct a maintainable representation of it. The two kinds of perception thus implied will be called "active" and "passive".

Method

The conditions in this experiment are illustrated in Figure 5 (a). Subjects performed in two separate sessions during one of which (session A) only the first three conditions occurred, while in the other (session B) all five conditions occurred. In both sessions the conditions occurred at random. Thus, in session A, subjects did not need to form a maintainable representation of pattern 2, while in session B formation of such a representation was required. The order in which the two sessions were administered was balanced across subjects.

The patterns in the form of 5×5 matrices were each displayed for $1{\cdot}5$ s. The retention interval in conditions 4 and 5 was $1{\cdot}5$ s in duration. Six subjects took part in this experiment. They each received £2.00 for their attendance at the two separate 1 h sessions. Each session contained 40 trials in each of the three or five conditions. In addition subjects were given a block of practice trials containing eight trials per condition at the beginning of each session.

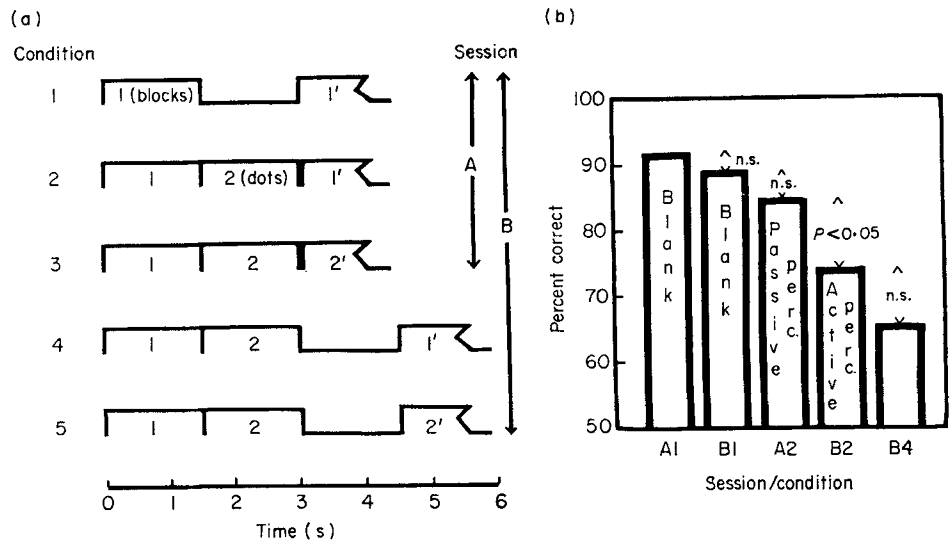

FIGURE 5. Experiment V. The effect of processing a dot pattern in different "contexts" on the visualization of a block pattern. (a) Method. 1′ etc. represents the test of pattern 1, etc. (b) Percentage of correct response to the block pattern as a function of session and condition. (Results for the dot pattern are given in the text.)

Results and discussion

The scores for condition 3, in which the dot pattern was tested immediately, were 94% in session A and 97% in session B. The score for condition 5, in which the dot pattern was tested after a delay, was 82%. These scores indicate that subjects were not "ignoring" the dot pattern: when it was tested, performance was high.

The numbers of correct responses in the remaining conditions (where the block pattern was tested) were subjected to a one-way analysis of variance which showed a significant effect of type of interference, $F\,(4,20) = 11{\cdot}34$, $P < 0{\cdot}001$.

The percentages of correct response over all subjects in these five conditions are shown in Figure 5(b) along with the results of the Newman-Keuls test by which the means were compared.

As predicted, there was a significant difference between performance on condition 2 in the context of passive perception of the dot pattern (session A) and performance in the identical condition in the context of active perception of the dot pattern (session B). The difference between active perception and active perception plus storage (conditions 2 and 4 in session B) approached but did not reach significance. The passive perception of the dot pattern (condition 2 in session A) did not cause significant interference as compared with the blank condition 1 in session A. Performance on condition 2, session B, however, differed significantly from the blank condition 1 in session B ($\alpha = 0{\cdot}05$). Thus active perception of the dot pattern produced significant interference.

Condition 2 of this experiment yields evidence of visual perception interfering with visualization. However, the results show that different task contexts can produce significantly different degrees of perceptual interference. Active perception clearly interferes with visualization, but passive perception causes little or no interference.

Final discussion

The above experiments have indicated a few of the conditions upon which interference with visualization depends. They support the view that visual perception can interfere with visualization, but also show that different perceptual processes interfere to different extents, and suggest that some may not interfere at all. A possible explanation of these results is that visual perception interferes with visualization only when it involves active formation of a maintainable representation of input. It is not surprising that the different visual tasks caused quite different amounts of interference with visualization because there is good evidence on other grounds that formation of representations that outlive the icon involves operations that are quite distinct from the visual processes dealing with sensory representations (Coltheart, 1972; Phillips, 1974). Furthermore, Experiment V shows that the occurrence of those perceptual processes that do cause interference depends upon the overall task requirements and possibilities within a sequence of trials, and not only upon the stimulus conditions within a single trial. This indicates that deployment of resources between visualization and perception is determined by a high level control process that views the situation as a whole.

Experiments I and II indicate that the recognition of visually presented digits causes little or no interference with visualization. The class of perceptual processes that we are suggesting causes such interference must, therefore, be further qualified. It seems as though interference depends less upon the representations formed than upon the processes involved in forming those representations. It may be that recognition of digits, being highly overlearned, involves mental operations that are pre-programmed, and that visualization is interfered with only by operations that are not pre-programmed. These two experiments also indicate that it is not only visual processing that interferes with visualization because adding five auditory digits seems to completely remove visualization. It is perhaps possible that the auditory digits are somehow added visually, but this seems unlikely, and if true would reduce the grounds for calling the visual processor involved "special purpose". Other experiments that we have run all seem to suggest that interference depends not upon whether the actions are visual but upon whether they are predictable and highly over-learned. What this all suggests is that the visualization studied here is not pre-programmed and that all actions that are not pre-programmed are controlled by a single central executive of some kind. Such an executive would seem to be essential whenever unique streams of behaviour are coherent, goal-directed and appropriate. Central executives of this kind have been proposed many times, but what we are suggesting is, perhaps, most similar to the working memory of Baddeley and Hitch (1974) and the selector input in Shallice's (1972) model of consciousness.

A single central executive may well be necessary for visualization, but does it perform that visualization itself or does it use a special purpose visualizer? It is usually thought that results such as those of Brooks (1967, 1968) show the latter to be the case, but we have suggested in the introduction that the arguments from this evidence are not strong, and we know of no other good evidence on the issue. In general terms it seems to be just as plausible to assume that a central executive of some kind performs the visualization as to assume that it does not. This important issue, therefore, seems to be unresolved. [Evidence for a special purpose visualizer might be provided by a task high in its demands upon such a processor but low in its demands upon a central executive, because such a task (or aspects of it) would interfere with visualization but not adding, whereas this could not be the case if visualization depended only upon a processor which it shared with adding. It has been suggested (Baddeley, private communication) that spatial tracking may be such a task but this possibility does not yet seem to have been explored.]

Our discussion so far has assumed that any interference specificity is due to separate processors, i.e. that it is due to resource limits rather than to interference between the representations involved. If this assumption is false, the results are much less interesting because it has been shown many times within classical associative theory that interference between items in memory depends greatly upon their "similarity". Interference dependent upon similarity of some kind would not imply separate processors or even separate forms of representation. For at least two reasons, however, similarity dependent interference seems unlikely to be a major factor in the above results. First, auditory digits are not very similar to random visual block patterns, yet adding them entirely removes visualized information. Second, the various intervening conditions in Experiments III, IV and V all used patterns that were very similar to those being visualized, yet the interference caused varied greatly depending upon the processing required.

It may be worth noting that performance of visualization by a central executive would not imply that there are no special purpose processors for other visual operations. Merikle (1976) found evidence that reading a single digit interfered with the processing of tachistoscopically presented letters more than did listening to a single digit. This apparent contrast with our results could be explained on the assumption of a special purpose visual processor of limited capacity used for the recognition of familiar items, but not for visualization.

In summary, the above results provide evidence that visualization requires general purpose resources. They also show that it is interfered with by visual perception and that it is interfered with more by some kinds of visual perception than others. They indicate that visual perception interferes with visualization only when it involves the active formation of schematic representations of novel visual configurations. Such perception may well be the rule rather than the exception, because nearly all the scenes we encounter are unique in the sense that even when the objects are familiar their arrangement is new. The kind of resources for which visualization and such perception are in competition is not yet clear, but it seems possible that they are in competition for general purpose rather than special purpose resources.

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