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Research Focus

Visual working memory depends on attentional filtering

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Working memory holds information actively being used in cognitive performance. Two important aspects of working memory are how many items it can hold, and how efficiently it can be used. Recently, Vogel and colleagues used event-related brain potentials to show that these two things are related. People who could remember more objects from a spatial array also more efficiently excluded irrelevant objects. The results raise important questions about what aspect of working memory is most fundamental.

Working memory, the brain system for holding and manipulating a small amount of information temporarily, is essential for many cognitive activities [1]. The relation between storage and processing of information in working memory is unclear but has been studied using individual differences. The predominant method has been to combine processing and storage requirements in complex tasks such as reading sentences and remembering the last word of every sentence for subsequent recall after several sentences [2], or carrying out arithmetic operations and remembering a word after each one for recall after several operations [3]. Individuals with higher scores in such tasks also are better at controlling their attention, in ways such as counteracting the impulse to look toward a suddenly-appearing object [4] or ignoring one's own name spoken in a channel irrelevant to the assigned task [5]. However, it has never been clear just how attention control might actually help an individual's working memory. One suggestion is that attention can be used to ensure that the limited available capacity is filled with relevant, as opposed to irrelevant, information [6,7]. Now Vogel, McCollough and Machizawa [8], with an ingenious use of event-related potential recordings, have show that high-ability individuals do indeed spare their capacities by filtering out irrelevant items from visual working memory.

Tapping into working memory

The basic procedure for assessing working memory is elegant [9]. A standard array of objects is briefly presented and then a second, comparison array is presented after a short interval – either identical to the first array or differing in a feature of one object. The observers' task is to indicate whether the comparison array has changed. This sort of task is easy with two or three objects per array and becomes increasingly difficult as the number of array objects increases beyond four. Vogel and Machizawa [10] further developed the procedure to allow measurement of a physiological marker of the maintenance of object information in visual working memory. By presenting several objects in each visual hemifield but indicating that the array in one hemifield must be retained for comparison, they were able to use electrical activity over the contralateral side of the scalp as an indicator of whether information was held in working memory. A clear signal was obtained, which increased with the number of array items in a manner closely resembling the behavioral marker – the capacity of working memory according to a formula that corrects for guessing [11]. Across individuals, working memory capacity correlated well with the increase in magnitude of the lateralized electrical signal between array sizes of 2 and 4 items.

The new study of Vogel *et al.* [8] added distracting stimuli. In Experiment 1, participants were required to compare the orientations of one color of bars (e.g. red), sometimes in the presence of irrelevant bars (e.g. blue; see Figure 1). In individuals with high working memory capacities, the brain correlates of remembering two relevant bars mixed with two distracters were similar to those of remembering two relevant bars with no distracters. In individuals with low capacities, though, the brain correlates of remembering two relevant bars mixed with two distracters were similar to those of remembering *four* relevant bars with no distracters. In low-capacity individuals, failure to filter out distracters presumably imposed a burden on visual working memory.

This result generalized beyond filtering by color. In Experiment 2, filtering occurred on the (easier) basis of location, and comparable results were obtained. Experiment 3 showed a similar pattern when working memory was filled in two phases, from an initial display followed by an intermediate display. Participants successfully appended relevant items from the intermediate display into a working memory composite to be compared with the final, integrated test array. However, low-capacity participants seemed in addition to append irrelevant items, which were suppressed by high-capacity individuals [8].

Many investigators of visual working memory have assumed an automatic, modality-specific memory faculty. However, the new data suggest that memory maintenance might be attention-demanding rather than automatic. Theoretically, the type of attention involved could be specific to vision. However, other data indicate that a general, amodal type of attention is involved. A memory

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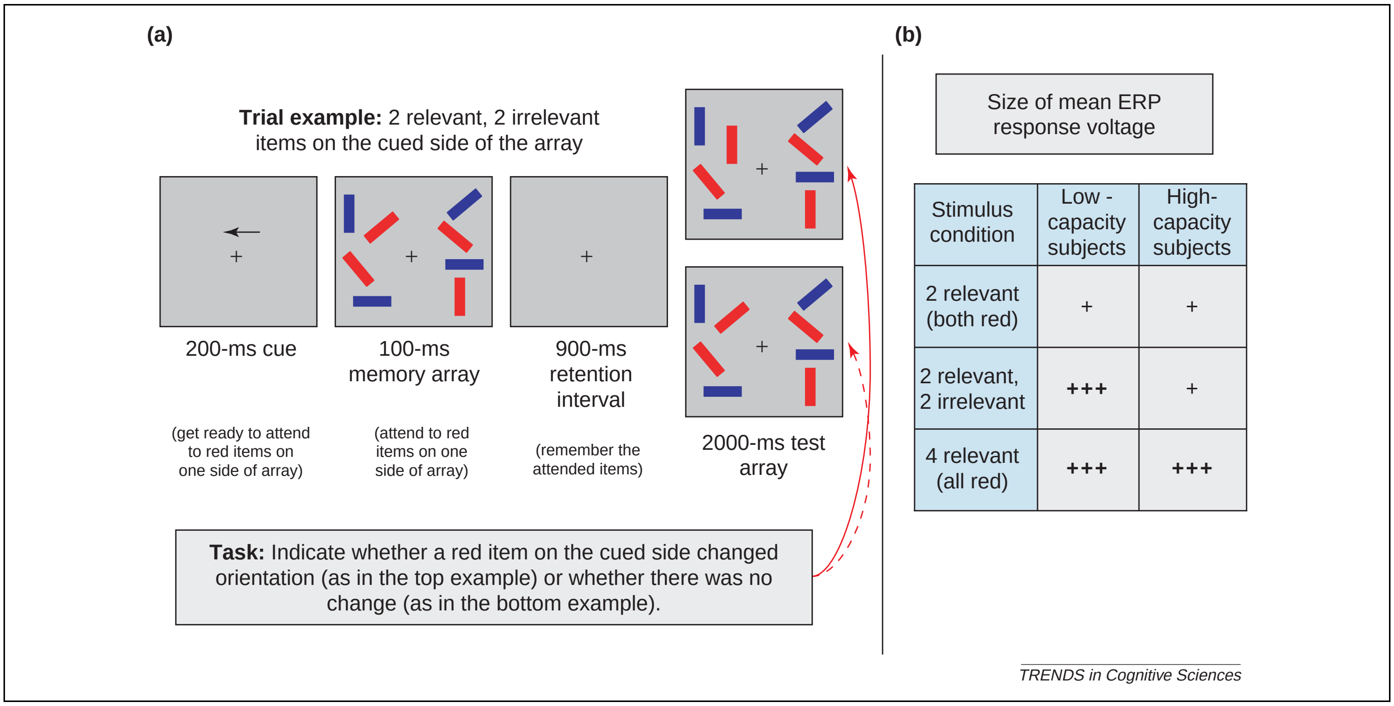

Figure 1. Method and results of Vogel *et al.*, Experiment 1 [8]. **(a)** Schematic illustration of the procedure: on each trial, an arrow cue indicated which side of the array the subject needed to retain for a later comparison with a second array. Previous instructions were given as to which item color (red or blue) to remember on the cued side. The second array was either identical to the first or differed in the orientation of one of the to-be-remembered items. **(b)** The results were measured by the magnitude of event-related potential (ERP) recordings that correlated with the extent to which visual working memory capacity was occupied by the items. Arrays with 2 relevant (e.g. red) and 2 irrelevant (e.g. blue) items were processed by low-capacity individuals like a homogeneous 4-item array but were processed by high-capacity individuals like a homogeneous 2-item array, with items of the irrelevant color excluded from working memory.

load of six or seven random, spoken digits to be recited aloud interferes with maintenance of a visual array [12]. This is not the result of recitation per se: unlike random digits, reciting a well-learned number has no effect [13].

Why do high-capacity individuals remember more?

Several unresolved issues for further research emerge from this picture. One of them is why individuals with better control of filtering have an advantage in remembering arrays *without* distracters. Perhaps it is because items in the task-irrelevant hemifield of the display in this procedure [8,10] function as distracters.

Alternatively, related mechanisms might affect the *scope* and *control* of attention [14]. For maximal performance, an individual's focus must efficiently zoom out to apprehend the most items, or zoom in to maintain the task goal despite interfering stimuli. If the same resources are needed for apprehending relevant items and filtering out irrelevant ones, then filtering should come at a cost. We would predict that capacity estimates obtained in the presence of distracters should not be quite as high as estimates obtained without distracters, even in high-capacity individuals.

Why do low-capacity individuals fail?

Second, it is unknown why low-capacity individuals fail to filter out the irrelevant items. Perhaps participants face a strategic choice. Performance depends on the transfer of information from sensory memory to a more consolidated, abstract form [15], and it might take extra effort to transfer it selectively. That extra effort should pay off, allowing array comparisons to consider relevant items only. Low-capacity individuals might forego this extra processing because, for them, it is uncomfortably effortful or self-defeating (as the extra effort might drain too many resources from the consolidation process). To explore this, the procedure could be altered to make it worthwhile for low-capacity individuals to filter, by including changes in irrelevant items between the standard and comparison arrays. If only an irrelevant item had changed, the correct answer would still be 'no change'. Then it might be impossible to accomplish the task by comparing the first and second arrays en masse; it might be necessary to filter out irrelevant items. Alternatively, it might be possible to detect any change first, and only afterwards judge its task-relevance. A reaction-time measure might detect that strategy.

It is possible that array comparisons could be based on an automatic form of memory storage (e.g. visual sensory memory) in addition to more attention-demanding, consolidated memory. Perhaps low-capacity individuals rely on pre-consolidation, sensory memory, which might necessarily include all items. If so, an interfering array mid-way between the standard and comparison arrays should degrade this sensory memory, forcing low-capacity individuals to use consolidated memory, and perhaps filtering.

What will behavioral data show?

Third, the behavioral data might also help to clarify the picture. In this case [8], the authors omitted detailed behavioral evidence (e.g. individual differences in capacity in sets with and without distracters). In future, it would be helpful to determine whether the observed individual differences can be obtained behaviorally without items in a task-irrelevant hemifield, so that all potential distracters are eliminated from what is defined as the no-distraction condition. It also is important to determine whether behavioral results can be extended to procedures involving non-spatial memoranda [2,3,5]. In addition to the specific results, the Vogel *et al.* study [8] shows that a combination of experimental, psychometric and physiological methods can strengthen our understanding of how the human mind processes information.

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Letters

Detecting deception by manipulating cognitive load

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The traditional arousal-based approach

Concern with crime and terrorism makes it increasingly important to be able to detect lying. Most lie detection tools used to date are arousal-based protocols. The majority of these protocols are based on the assumption that, because of their fear of being caught, liars will be more aroused when answering key relevant questions (‘*Did you steal the money?*’) than when answering comparison questions. According to the US National Research Council’s well-documented report [1], however, this premise is theoretically weak. Liars do not necessarily reveal more signs of arousal when answering key questions. Conversely, truth tellers might be anxious and hence show signs of arousal when answering key questions.

Another arousal approach to detecting deception is based upon the premise that liars will show enhanced orienting responses when they recognize crucial details about the crime in the key questions [2]. Suppose a body was found in the kitchen, but the suspect denies knowledge of the crime. The suspect could then be asked where the body was found: ‘*in the bedroom, bathroom, kitchen or living room?*’ Interview protocols designed to demonstrate orienting responses could be difficult to apply, however, because they require the examiner to possess specific knowledge about the crime, and also because they require impractically sophisticated equipment to measure physiological responses (e.g. skin conductance, EEG).

The innovative cognitive-load approach

Given the theoretical weakness of the fear-based arousal approach and the practical difficulties of the orienting-based arousal approach, we propose a new approach to discriminate between liars and truth tellers. This novel approach rests on the premise that, in interview settings, lying is cognitively demanding. This extra cognitive demand is caused by liars having to engage in additional tasks: inferring what others are thinking, ‘keeping their story straight’ and monitoring and controlling their behaviour so they avoid creating the impression of lying.

Many sources support the premise that lying is cognitively demanding. First, in police interviews with real-life suspects, lies are accompanied by increased pauses, decreased blinking, and, for males, decreased hand and finger movements, all of which are signs of cognitive load [3,4]. Second, police officers who saw videotapes of interviews with suspects judged that the suspects were thinking harder when they lied than when they told the truth [5]. Third, participants in mock-suspect experiments directly assessed their own cognitive load during interviews and reported that lying was more

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