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Visual Working Memory Depends On Attentional Filtering

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Abstract

Working memory holds information actively being used in cognitive performance. Two important traits of working memory are how many items it can hold, and how efficiently it can be used. Recently, Edward Vogel and others used event-related brain potentials to show that these traits 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 working memory trait 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 shown that high-ability individuals do indeed spare their capacities by filtering out irrelevant items from visual working memory.

Methods and Findings of Vogel et al. [8]

The basic procedure is elegant [9]. A standard array of objects is briefly presented and then a second, comparison array is presented shortly afterward, identical to the first array or differing in a feature of one object. The task is to indicate whether the comparison array has changed. That sort of task is easy with 2 or 3 objects per array and becomes increasingly difficult as the number of array objects surpasses 4. Vogel and Machizawa [10] further developed the procedure to allow physiological measurement of the maintenance of object information in visual working memory. By presenting several objects in each visual hemifield but indicating that one hemifield must be retained for comparison, they were able to use electrical activity over the contralateral side of the scalp to indicate that 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 result, the capacity of working memory according to a formula correcting 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 [8] added distracting stimuli. In Experiment 1, participants were 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.

The 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 to the final, integrated test array. However, low-ability participants seemed to append irrelevant items as well, whereas high-ability individuals suppressed them [8].

Many investigators of visual working memory have assumed an automatic, modality-specific memory faculty. However, the new data suggest that memory maintenance may 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 load of six or seven random, spoken digits to be recited aloud interferes with maintenance of a visual array [12]. This is not an articulation effect, inasmuch as recitation of a well-learned number is ineffective [13].

Why Do High-Capacity Individuals Remember More?

There are several unresolved issues for further research. 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 may 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 failed to filter out the irrelevant items. Perhaps participants faced 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. It still might be possible to detect any change first, and only afterward judge its task-relevance, but a reaction time measure might detect that strategy.

Possibly, array comparisons can 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 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]. The new study [8] shows that a combination of experimental, psychometric, and physiological methods can strengthen our understanding of the human mind.

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Figure 1. Method and results of Vogel et al. [8], Experiment 1

The left-hand portion of the figure (yellow background) describes the procedure. On each trial, an arrow cue indicated which side of the array was to be retained for a later comparison with a second array. There were prior instructions as to which color of items 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. The right-hand portion of the figure (green background) summarizes the results, which were measured by the magnitude of event-related potential (ERP) recordings that reflected 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.