Target article: N. Cowan - The Magical Number 4

Commentary title:

Four-sight in hindsight: The existence of magical numbers in vision

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Abstract:

The capacity of visual attention/STM can be determined by change-detection experiments. Detecting the presence of change leads to an estimate of 4 items, while detecting the absence of change leads to an estimate of 1 item. Thus, there are two magical numbers in vision: 4 and 1. The underlying limits, however, are not necessarily those of central STM.

Main text:

In his target article, Cowan provides a wide-ranging review of data supporting the existence of a "magical number 4"--a common limit on the capacities of various perceptual and cognitive mechanisms. He suggests (section 3.1.1) that a similar limit may apply to change blindness, the finding that large changes become difficult to see when information about the location of the change is swamped by concurrent transients elsewhere in the visual field (Rensink et al., 1997; Simons, 1996).

In a typical change-blindness experiment, an original and a modified image of a real-world scene are presented in succession, with a brief blank field between them; alternation continues until observer detects the change. Even though the changes are large and the observer knows they will occur, several seconds are often required before a change is seen. This has been explained by the hypothesis that focused attention is needed to see change (Rensink et al., 1997). Given that focused attention can be largely identified with visual STM (vSTM), and that vSTM has a limited capacity, only a few items can be attended at any time. Thus, the detection of change requires a time-consuming attentional scan of the image.

But how many items can be attended at any one time? (Or, equivalently, how many can be held in vSTM?) This can be determined from change-detection experiments based on arrays of simple items (Rensink, 2000a). The critical parameter here is on-time (the length of time each array is visible during a cycle). The time needed to detect a changing target item among nonchanging distractors depends linearly on the number of items in the display. For orientation change, the slope of this function (i.e., search speed) is much the same for all on-times up to 600 ms, indicating that the rate-limiting step is one of processing rather than memory. But for on-times of more than 600 ms, speed becomes proportional to alternation rate, indicating that only a limited amount of information can be held in vSTM at each alternation--more display time does not allow more items to be entered into memory. When the interstimulus interval (ISI) between displays is 120 ms, this limit is 5-6 items (Rensink, 2000a). Further experiments have shown this to be a compound limit: when a short-term--presumably iconic--component is eliminated by increasing ISI to 360 ms, the estimate falls to 3-4 items (Rensink et al., 2000).

As Cowan points out, it is important to establish the absence of rehearsal or recoding processes that might cause estimates to be artificially high. For change detection, this is straightforward. First, the situation is one of information overload: not all the visible items can be placed into memory. Second, little recoding or rehearsal can occur (at least for cycle times of a second or less), since most of the available time is spent either loading items into memory or comparing them with the current input. Third, capacity is determined by a genuine discontinuity in performance, viz., a proportionality constant that appears when on-times are 600 ms or greater (Rensink, 2000a). Finally, the estimate is largely unaffected by temporal decay: if ISI is greater than 360 ms, there is little further decrease, even for intervals as high as 8 s (Schneider et al., 1999). Thus, the magical number 4 does seem to exist.

But the story does not stop here. If targets and distractors are switched so that the subject must detect a non-changing target among changing distractors, a different limit is reached: 1.4 items (Rensink, 1999, 2000b). This suggests that attended items are not independent but are instead pooled into a single collection point, or nexus (Rensink, 2000b). Such a "magical number 1" may correspond to the limit alluded to by Cowan in his proposal that "the [4 separate] parts are associated with a common higher-level node" (section 2.6).

As such, there is considerable support for the claim of at least two magical numbers in vision. However, there is less support for the claim that these are due entirely to limitations on a central working memory. To begin with, the long-term memory units (or chunks) accessed by STM need not be the same as the vSTM units (or parts) obtained from the visual input. A particular configuration might be a unit for purposes of memory retrieval, but not for visual operations such as tracking or attentional suppression. Different kinds of processes are likely to be involved, and thus, different kinds of units.

As an illustration of this, consider the detection of change in contrast sign. Whereas capacity for orientation is 3-4 items, capacity for contrast sign is at least 10 items (Rensink, 2000a, 2000c). This is likely to be a compound limit, resulting from the grouping of items of similar contrast sign. But note that such groups are purely short-term visual structures--there is little likelihood that any particular arrangement had been seen before and became a chunk in long-term memory.

More generally, perception and cognition rely on systems which interact with each other to a high degree, making it difficult to determine the locus of performance limits. Indeed, there may not even be a single locus: performance on a visual task may involve both visual structures (parts) and memoric structures (chunks); a magical number might represent the number of degrees of freedom on a structure linking the two levels. Given that there are no compelling a priori grounds which can be appealed to, this matter will have to be settled by experiment. (The issue of individual differences would seem to be a particularly good candidate in this regard.) Until such experiments are carried out, it may be best to keep our options open as what causes the magic in our visual world.

References

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