Your Inner Spam Filter

What makes you so smart? Might be your **lizard brain**

By Andrew W. McCollough and Edward K. Vogel

FAST FACTS

Limits of Processing Power

1» Our mental "in-box" of working memory—the brain regions and processes that keep something "in mind"—is limited to a very few items at a time. Differences in working-memory capacity are directly related to abstract-reasoning abilities.

2» Two factors are thought to limit working memory: overall storage space and total space efficiency.

3» High-capacity individuals (who tend to do better on aptitude tests) might simply be better at keeping irrelevant information out of mind, whereas low-capacity individuals may allow unneeded data to clutter the mental in-box. A new study suggests that such filtering is key.

Anyone who has tried to find an urgent e-mail amid masses of advertisements for dubious stock opportunities and sexual-enhancement drugs understands the critical importance of being able to filter out distracting information. That e-mail you seek may be in there, but it is lost among irrelevant clutter.

Although the capacity of our computer's e-mail in-box is limited only by disk space, our mental "in-box" of working memory—the brain regions and processes that create temporary storage—is much more constrained. In fact, several decades of research have indicated that our capacity to hold information "in mind" for immediate use is limited to a mere three or four items.

Moreover, just as people vary in height and eye color, they also vary in the capacity of this memory in-box. Interestingly, these differences in working-memory capacity are strongly predictive of a person's ability to perform abstract reasoning, mathematics and other forms of complex problem solving. This relation between memory capacity and fluid intelligence has motivated many scientists to try to understand why and how people differ in this important cognitive ability. A new study adds insights into that line of inquiry.

Hard Drive or Spam Filter?

There are two primary explanations for this severe limitation in working-memory capacity. First, it could be that storage space essentially determines working memory's limits and that some people have larger "hard drives" than others do. The alternative theory is that capacity depends not on the amount of storage but on how efficiently that space is used. Thus, high-capacity individuals (who can remember more information at once and who tend to do better on aptitude tests) might simply be better at keeping irrelevant information out of mind, whereas low-capacity individuals may allow more irrelevant information to clutter up the mental in-box. The difference may just be a matter of having better spam filters.

Some of our own recent work on differences in controlling access to working memory has provided evidence favoring this mental spam-filtering idea. In one experiment, measuring electrical signals emitted by the brain enabled us to show that high-capacity

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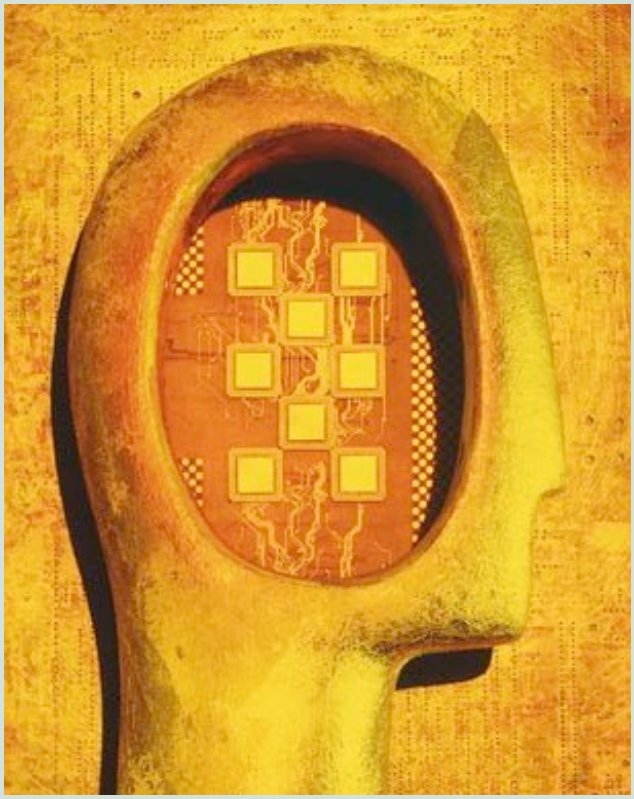

BY NELSON COWAN

Mental spam filters in our basal ganglia may strongly affect the capabilities of working memory [*see main article*]. Inefficient spam filters permit needless, excess activity in the brain regions that actually store working-memory information—including the posterior parietal areas, along the top of the brain toward the back. In working-memory operations, these parietal areas hold information briefly, from the time it is presented until it can be used.

And there is more to the story. These parietal areas function here not so much as the permanent storage of a hard drive but rather as the temporary storage of random-access memory, or RAM, where information is held when it is in use or might soon be used. And although evidence points to the importance of the efficiency of filtering irrelevant items from working memory, we must be careful not to overlook the possibility that differences in RAM capacity also affect working memory. If RAM size does matter, then RAM size and filtering efficiency may be imperfectly correlated. By analogy, individuals' top sprinting speeds and endurances may be imperfectly correlated, even though both qualities depend on certain common factors, such as health.

In fact, evidence suggests that the RAM-storage capacity of working memory is important. In a study published in 2005 in Cognitive, Affective, & Behavioral Neuroscience, neuroscientists Andrew W. McCollough and Edward K. Vogel found that people were excellent at controlling what information was represented in working memory: they let in information about relevant objects but completely filtered out that about irrelevant objects. Low-capacity individuals, in contrast, had much weaker control over what information entered the mental in-box; they let in information about both relevant and irrelevant objects roughly equally. Surprisingly, these results mean that we found that low-capacity people were actually holding more total information in mind than high-capacity individuals were—but much of the information they held was irrelevant to the task.

Where Is the Filter?

So the evidence is amassing that your mental spam filter largely establishes your working-memory capacity. Yet a critical question remains unanswered. Where in the brain does this spam filter reside?

According to a study published this past January in *Nature Neuroscience,* neuroscientists Fiona McNab and Torkel Klingberg of the Stockholm Brain Institute appear to have found its location. To do so, they had participants perform a working-memory task in which they had to recall the positions of red and yellow squares on a computer screen. Sometimes they were asked to remember all the items on the screen (both red and yellow), and other times they were asked to keep track of just the red items and to forget the yellow items—an act akin to filtering spam. A symbol presented at the start of each trial told them whether they had to focus on just red squares or let all the information from the display flow into memory. The researchers recorded the subjects' brain activation using functional MRI scans during this instruction period as a way of determining what parts of the brain became active as a person started up the mental spam filter.

McNab and Klingberg found that when participants were told they would need to filter the upcoming trial, parts of the basal ganglia (an area known to be important in movement, among other tasks)

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entists J. Jay Todd and René Marois of Vanderbilt University showed that brain activity in the posterior parietal areas—the working-memory "RAM"—correlated with working-memory performance even though the task at hand did not require much filtering.

Additional behavioral experiments have reinforced their conclusion. In a study of normal and schizophrenic adults published in 2006 in the *Journal of Abnormal Psychology,* neuroscientist James M. Gold of the Maryland Psychiatric Research Center at the University of Maryland School of Medicine and his colleagues tested subjects' memory for items, some of which they had been told they could ignore. Compared with normal control subjects, schizophrenic patients remembered fewer items across the board. That is, they remembered fewer of the items they were told to remember and fewer of those they were told they could ignore. Yet both control subjects and people with schizophrenia did far better remembering "attended" items than items they were allowed to disregard. Filtering efficiency, in other words, was about equal in the two groups.

Meanwhile a 2006 study from my own lab published in *Memory & Cognition* showed that the storage capacity and filtering efficiency of working memory were partly related and partly distinct—something like the sprinting-to-endurance relation suggested above. Not every higher-capacity participant was able to filter out irrelevant items very efficiently, for example.

This panorama of results demonstrates that both storage capacity and filtering efficiency affect an individual's working-memory ability. New methods for analyzing the brain do not necessarily replace older ones—just as automobiles did not replace bicycles, which did not replace walking. To find the whole truth, brain-imaging methods must be used along with older behavioral methods and philosophical reasoning about the mind. Back in 1971, in an essay entitled "Art in Bits and Chunks," the late perceptual psychologist Rudolf Arnheim suggested that a psychologist's most important tool is the armchair. The statement still rings true for brain research.

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and the prefrontal cortex (considered to be the brain's rationalizing, "thinking" part) became much more active than in the nonfiltering trials. And the researchers found that the jump in activity levels in these areas was largest for high-capacity individuals and smallest for low-capacity individuals. That is, when told they needed to filter, the high-capacity individuals ramped up activity in these brain regions to keep out irrelevant items. In contrast, the low-capacity individuals showed little additional activity in these areas when they were instructed to ignore the extraneous items. Thus, a leading candidate for the mental spam filter appears to be a cooperative effort between the basal ganglia and the prefrontal cortex.

In this filtering mechanism, the prefrontal cortex most likely provides details about the current task goals and the basal ganglia lend the mental muscle to block out information that does not match these goals.

This role for the basal ganglia in helping to control the flow of information into working memory is quite similar to one of the basal ganglia's other major functions, which is selecting which motor movements to use in a given context and suppressing the movements we do not want. Particularly intriguing is that the basal ganglia are evolutionarily ancient brain structures that have been highly conserved across species; even lizards have them. Consequently, what is thought to be our uniquely human ability to engage in abstract reasoning and problem solving appears to be dependent on brain structures that have been around for far longer than humans have. The ability to filter out irrelevant spam, it seems, is critical for lizards as well as humans. M

When volunteers in a study were asked to perform a filtering task—they had to remember certain colored squares and ignore other squares on a computer display—areas of their basal ganglia, an area known to be involved in movement (*right*), and prefrontal cortex, associated with making rational judgments (*left*), became more active.

(Further Reading)

- **The Magical Number 4 in Short-Term Memory: A Reconsideration of Mental Storage Capacity.** Nelson Cowan in *Behavioral and Brain Sciences,* Vol. 24, No. 1, pages 87–114; February 2001.
- **Neural Measures Reveal Individual Differences in Controlling Access to Working Memory.** Edward K. Vogel, Andrew W. McCollough and Maro G. Machizawa in *Nature,* Vol. 438, pages 500–503; November 24, 2005.