Think fast: Speed of thought and perception limited by unified neocortical gateway

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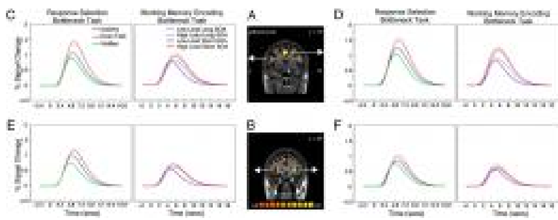

BOLD response amplitudes and latencies for the response selection (Experiment 1) and encoding bottleneck (Experiment 3) tasks. (A) Typical participant's SPM of the conjunction of the AV open contrast and VM open contrast showing aSMFC and IFJ ROIs. (B) Left and right hemisphere insula ROIs. (C-F) Curve-fitted BOLD time courses across frontal brain regions for the AV, VM, and dual-task trials in Experiments 1 (Left) and 3 (Right). (c) PNAS, doi: 10.1073/pnas.110358310

(Medical Xpress) -- Historically, perceptual and response rates when multitasking have been interpreted as being limited by independent bottlenecks. While a more recent view suggests that a common bottleneck might be the cause, experimental evidence for its existence have not been determinative. Recently, however, researchers at Vanderbilt University used time-resolved *functional magnetic resonance imaging* (fMRI) – where both the topography and temporal sequence of cortical activation across brain regions is examined – to identify a *unified attentional bottleneck* – a network of regions that apparently limits the speeds at which perceptual encoding and decision-making can occur.

The research, conducted by a team of researchers led by Michael N. Tombu at Vanderbilt University's Marois Lab, found that the inferior frontal junction, superior medial frontal cortex, and bilateral insula are directly involved in capacity limited processing. The experimental design utilized three interrelated experiments: The first imaged isolated brain regions involved in response selection; the second imaged the same areas during perceptual encoding' and the third tracked decision-making delays caused by concurrent perceptual encoding.

Tombu points to two techniques that were critical to demonstrating the existence of a previously hypothetical unified attentional bottleneck neural structure. "Identifying timing differences across conditions was critical to the investigation, and both of the techniques we leveraged relate to measuring timing. Generally speaking, fMRI is known for good spatial resolution and bad temporal resolution. Techniques like the electroencephalogram (EEG) are better known for good temporal precision, but they have bad spatial resolution. In the present study we used an interleaved acquisition to double our temporal resolution in the first experiment."

To do this, Tombu explains, they started half of the trials at the beginning of an fMRI data acquisition and the other half halfway through an acquisition. "By acquiring data points at twice the number of locations along the hemodynamic response function, a better defined HRF can be established, effectively doubling the temporal resolution of the experiment."

Secondly, Tombu and his colleagues improved temporal resolution by restricting spatial coverage to regions identified in the first experiment and using these savings to increase the temporal resolution of the acquisitions in the second and third experiments. "This really let us get a good picture of the relative timings of neural events in those later experiments with decent spatial resolution, which was crucial to resolving the questions we wanted to answer."

Almost all current fMRI research uses *blood-oxygen-level dependence* (BOLD) – the MRI contrast of blood deoxyhemoglobin, or oxygen desaturation – as the method for specifying where activity occurs in the brain as the result of various experiences, and the current research was no exception. The team used BOLD to determine where brain activity occurred as subjects where engaged in perception and response while multitasking. Some researchers question BOLD because its signals are relative and not individually quantitative, and so are looking towards other methods of measuring neural activity such as oxygen extraction fraction (OEF) or direct detection of neural current-generated magnetic fields – but because the electromagnetic fields created by an active or firing neuron are so weak, the signal-to-noise ratio is extremely low and statistical methods used to extract quantitative data have been largely unsuccessful as of yet. Tombu agrees, pointing out that "although you could probably use positron emission tomography (PET) or magnetoencephalogram (MEG) in the present investigation, each has its own drawbacks and advantages – and would likely confirm what we've already shown. I think BOLD is a good proxy for neural activity."

That said, Tombu notes, "In my opinion there are existing techniques and tools that can be applied to the research questions examined in our paper that provide the next logical steps to better understanding the capacity limitations that dominate human information processing. Specifically, I think that transcranial magnetic stimulation (TMS) will be able to shed some light on the specific roles of different components of the bottleneck network we've identified. Now that we have identified some of the regions that appear to be critical to bottleneck processing, TMS can examine the consequences of deactivating nodes within that network. Neural decoding – a technique we've previously used – is another technique that can be brought to bear on this problem space."

Tombu adds that "Given our focus on timing, any techniques that improve the temporal resolution of the data acquisition would be welcomed."

The resulting fMRI data were analyzed using ANOVA (the ANalysis Of VAriance between groups), says Tombu, "primarily to examine timing and amplitude differences across conditions. These analyses were performed largely on fit parameters derived from regions isolated from the statistical parametric maps (SPMs)." Although there are alternatives to ANOVA, Tombu points out that "in our previous work we used ANOVA, and we wanted to be able to make parallels with that work. Using a different technique would have injecting unnecessary noise into our system. Moreover, my expectation is that our results would have been largely the same using other techniques such as fuzzy clustering or independent component analysis (ICA).

In terms of applications, Tombu says that their research findings answer an outstanding question from the cognitive psychology literature about the existence of a unified bottleneck for memory encoding and response selection. "Our results establish that bottleneck processes for both operations are collocated, and in all likelihood also being carried out by the same populations of neurons. This has implications for theory and also leads very naturally to future work that will better define exactly how the brain deals with the problem of limited resources in a world of unlimited possibilities. In the longer term, this may have implications for how computers are designed to deal with exactly the same problem. As we speak, IBM is already developing chips that behave more like neurons in the brain, capable of learning through processes akin to synaptic connections, to develop what the company calls *cognitive computing*. If we can establish how the brain deals with problems of limited capacity, these principles may also be applied to cognitive computing as well."

Regarding potential medical applications, Tombu notes that numerous disorders relate to attentional deficiencies. "Our research speaks directly to the neural mechanisms responsible for the deployment of attention in a range of situations including encoding and response selection. Isolating such a network may help focus research on the potential neural correlates of these disorders."

Taking a larger view, Tombu comments that "Work such as that conducted in the present paper using one technique is all well and good and tells us something about how the brain is working, but perhaps its real value is that it informs the field, allowing additional techniques from single cell recording work in non-humans to neuropsychological investigations of abnormal populations to be applied to the same problem. "

More information: A Unified attentional bottleneck in the human brain, Published online before print August 8, 2011, doi:10.1073/pnas.1103583108, *PNAS* August 8, 2011