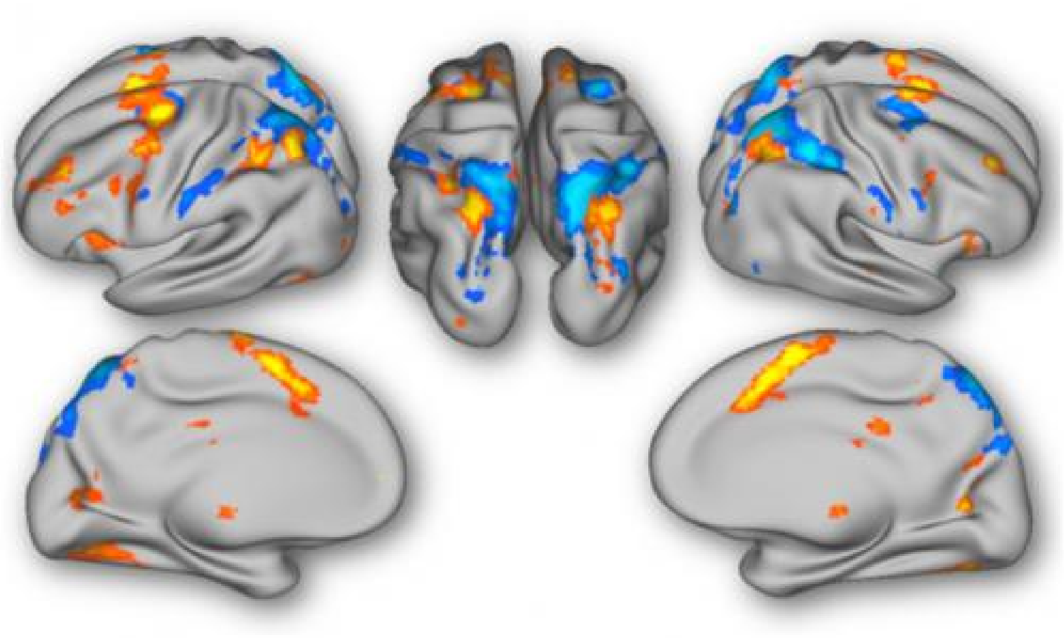
Medical Xpress

To predict, perchance to update: Neural responses to the unexpected

September 24 2013, by Stuart Mason Dambrot



Uncorrected whole-brain activity patterns for surprise (IS) and updating (DKL). These maps are not corrected for multiple comparisons, and hence are shown only to give an impression of the overall pattern of activity that underlies the multiple comparisons-corrected effects reported in the main text. The maps are thresholded at Z > 2.0 uncorrected. Blue colors indicate surprise, and red/yellow colors indicate updating. Copyright © PNAS, doi:10.1073/pnas.1305373110

(Medical Xpress)—Among the brain's many functions is the use of predictive models to processing expected stimuli or actions. In such a model, we experience *surprise* when presented with an unexpected stimulus – that is, one which the model evaluates as having a low probability of occurrence. Interestingly, there can be two distinct – but often experimentally correlated – responses to a surprising event: reallocating additional neural resources to reprogram actions, and updating the predictive model to account for the new environmental stimulus. Recently, scientists at Oxford University used brain imaging to identify separate brain systems involved in reprogramming and updating, and created a mathematical and neuroanatomical model of how brains adjust to environmental change, Moreover, the researchers conclude that their model may also inform models of neurological disorders, such as extinction, Balint syndrome and neglect, in which this adaptive response to surprise fails.

Research Fellow Jill X. O'Reilly discussed the research she and her colleagues conducted with *Medical Xpress*. "Sometimes we think of the brain as an input-output device which takes sensory information, processes it, and produces actions appropriately – but in fact, brains don't passively 'sit around' waiting for sensory input," O'Reilly explains. "Rather, they actively predict what is going to happen next, because by being prepared, they can process stimuli more efficiently."

O'Reilly cites an important example of predictive processing, which the researchers used in their study: the control of eye movements. "You can actually only process quite a small portion of visual space accurately at any one time, which is why people tend to actively look at interesting objects," O'Reilly tells Medical Xpress. "Parts of the brain that control eye movements – for example, the parietal cortex – are actively involved in trying to predict where visual objects that are worth looking at will occur next, in order to respond to them quickly and effectively." Since the scientists were interested in how the brain forms predictions – such as where eye movements should be directed – they designed an experiment in which people's expectations about where they should make eye movements were built up over time and then suddenly changed. (They did this moving the stimuli participants' were instructed to fixate on to a different part of the computer screen.)

"However," notes O'Reilly, "we know from previous work that activity in many brain areas is evoked when people are expecting to make an eye movement to one place, and actually they have to make an eye movement to another. A lot of this brain activity has to do with reprogramming the eye movement itself, rather than learning about the changed environment. That means we needed to design an experiment in which re-planning of eye movements was sometimes accompanied by learning, and sometimes not." The researchers accomplished this by color-coding stimuli: participants knew that colorful stimuli indicated a real change in the environment, while grey stimuli were to be ignored.

To quantify how much participants learned on each trial of the experiment, the team constructed a *computer participant* that learned about the environment in the same way the real, human participants did. Because they could determine exactly what the computer participant knew or believed about the environment – that is, where it would need to look – on each trial, we could get mathematical measures of how surprising it found each stimulus (defined as how far the stimulus location was from where the computer participant expected it to be) and how much it learned on each trial.

Therefore, the computer participant allowed the scientists to separately measure the degree to which human participants had to respond to surprise in terms of reprogramming eye movements, and how much they learned on each trial. "We then needed to work out whether some parts of the brain were specifically involved in each of these processes," O'Reilly continues. "To do this we used fMRI and looked for areas that increased their activity in proportion to how much the computer participant, and thereby the real participants, would need to reprogram their eye movements for each surprising stimulus – as well as the extent to which they'd have to update their predictions about future stimulus locations – on each trial."

O'Reilly stresses that the computer participant was critical to addressing the challenges they encountered. "We had access to a complete model of what participants could know or should believe about where stimuli were expected to appear on each trial. That meant we could make very specific predictions about how much they should be surprised by certain stimuli and how much they learned from each stimulus." The team checked these predictions by looking at behavioral measures like reaction time (participants were slower to move their eyes to surprising stimuli) and gaze dwell time (participants looked at stimuli for longer when the stimuli carried information about the possible locations of future stimuli).

O'Reilly describes how their study may inform understanding of neurological disorders in which this adjustment process fails by observing that a second saccade-sensitive region in the inferior posterior parietal cortex was activated by surprise and modulated by updating. "Some stroke victims are unable to move their eyes in order to look at stimuli that show up in their visual periphery, which turns out to be similar to the process of reprogramming to surprising stimuli in our model. In contrast," she continues, "people with brain lesions in a slightly different brain region are able to move their eyes to look at stimuli, but seem unable to learn that stimuli could occur in some parts of space – usually towards the left of the body – even if given lots of hints and training." Because the brain regions damaged in these two patient groups map onto the regions of parietal cortex active in the experiment's reprogramming and updating conditions, the researchers think these two processes could be differentially affected in the two patient groups.

Moving forward, the researchers would like to test their paradigm in patients who have had strokes that damaged the different brain regions activated in their study. "We'd expect to find a difference between patients with damage in different parts of parietal cortex, such that one group might be slower to reprogram eye movements to all surprising stimuli whether these stimuli are informative about future stimulus locations or not," O'Reilly concludes, "whereas the other group might have trouble learning that the location where stimuli are going to appear has changed."

More information: Dissociable effects of surprise and model update in parietal and anterior cingulate cortex, *PNAS* September 17, 2013 vol. 110 no. 38 E3660-E3669, doi:10.1073/pnas.1305373110

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Citation: To predict, perchance to update: Neural responses to the unexpected (2013, September 24) retrieved 25 July 2024 from
https://medicalxpress.com/news/2013-09-perchance-neural-responses-unexpected.html

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