

## Following your heart

Joel S Winston & Geraint Rees

**A finding now suggests that the brain's response to heartbeats is influential in guiding reported visual experience, such that the ability to accurately report the presence or absence of a visual target is influenced by the brain's heartbeat-evoked activity.**

For several hundred years, you might have struggled to find a scientist willing to back Aristotle's claim that the heart, rather than the brain, is the "seat and source of sensations"<sup>1</sup>. But heartbeat-evoked neural activity is detectable across large areas of human neocortex (summarized in ref. 2). Why so much of the brain needs to know what is going on in the heart is puzzling, particularly given that most of the regulation of the heartbeat is involuntary and controlled by local and brain-stem reflexes. New work from Park *et al.*<sup>3</sup> suggests that a seemingly trivial perceptual capacity, the ability to accurately report the presence or absence of a visual target, is heavily influenced by changes in brain activity tied to the heartbeat.

Historically separate lines of research have addressed two questions that have intrigued neuroscientists. First, do apparently spontaneous fluctuations in neural activity influence behavior and conscious experience? Second, to what extent does the brain process events occurring in the body?

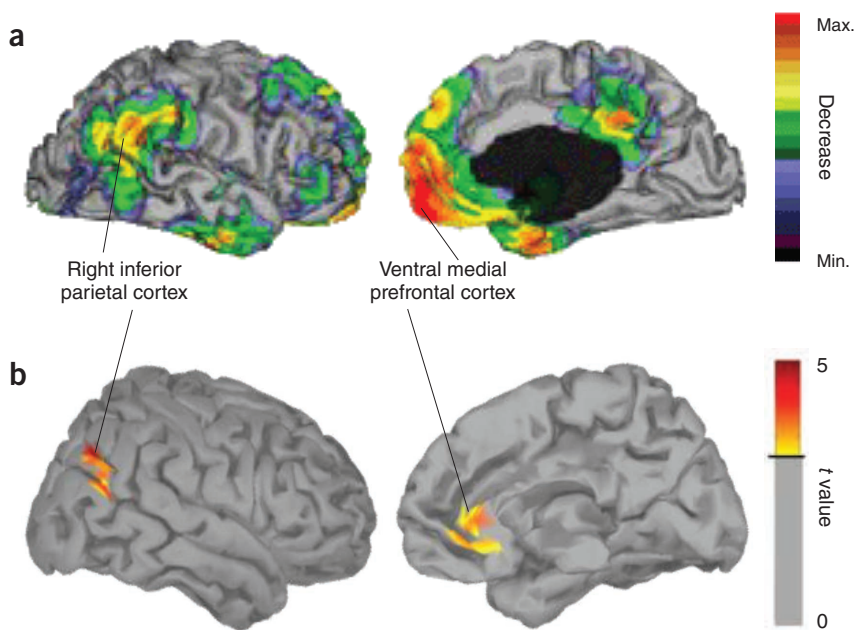
The observation that spontaneous fluctuations in neural activity heavily influence cortical responses to individual sensory stimuli was first made by Arieli *et al.*<sup>4</sup>. Such variation in neural activity while at 'rest' (that is, between experimental stimuli) has been demonstrated across multiple species and recording techniques and affects brain responses, perception and motor actions evoked by a stimulus<sup>5,6</sup>. An open question remains as to whether such spontaneous fluctuations are truly spontaneous or whether they might reflect other dynamical causes in the organism.

That bodily events influence perception and action has been acknowledged for quite

some time; Aristotle's stance toward the true location of perception was presumably influenced by introspection regarding experience during extreme emotion as well as reflecting the scientific knowledge of his day<sup>1</sup>. In modern science, the important influences of bodily events was more coherently connected to psychological experience by William James and other psychologists in the late nineteenth century (for example, ref. 7) through to more modern approaches to psychophysiology (for example, refs. 8–10). Of particular interest is the fact that the timing of stimuli relative to the

heartbeat cycle can influence stimulus-evoked neural responses and stimulus perception<sup>9–12</sup>. Moreover, individual heartbeats themselves evoke cortical responses (the heartbeat-evoked potential) detectable with precise electrophysiological techniques<sup>2,13</sup>.

This was the starting point for Park *et al.*<sup>3</sup>. Combining these two lines of research, they looked for spontaneous fluctuations in heartbeat-evoked responses (the magnetoencephalographic equivalent of heartbeat-evoked potentials) that preceded a visual stimulus presented at detection threshold (that is, participants were equally



**Figure 1** Overlap of the results from Park *et al.*<sup>3</sup> with the default mode network. (a) Regions of the brain that show task-independent decreases in activation across functional imaging experiments (after ref. 15; images courtesy D. Van Essen and A.Z. Snyder), also referred to as nodes in the default mode network. (b) Park *et al.*<sup>3</sup> show that the magnitude of heart-evoked responses to heartbeats preceding a visual stimulus in right inferior parietal cortex and ventral medial prefrontal cortex predict successful detection of the stimulus (adapted from ref. 3). Note how the identified areas fall within two of the key nodes of the default mode network.

Joel S. Winston and Geraint Rees are at the Institute of Cognitive Neuroscience and Wellcome Trust Centre for Neuroimaging, University College London, London, UK.

e-mail: [joel.winston@ucl.ac.uk](mailto:joel.winston@ucl.ac.uk)

likely to report perceiving or not perceiving the stimulus). There were striking differences in heartbeat-evoked responses that preceded those trials during which the target was perceived compared with those in which it was not seen. These differences predominantly localized to two cortical regions, right posterior parietal and ventromedial prefrontal cortex. The authors carefully eliminated a number of possible confounding factors, including general cortical excitability and specific measures of bodily arousal, as likely explanations of the differences.

One of the important ways that this work extends our understanding is by demonstrating the importance of brain-body interactions in apparently 'cold' cognition. The visual stimulus used by Park *et al.*<sup>3</sup> had no intrinsic emotional value and performance on the task was not rewarded directly. Yet the brain's response to its body before the appearance of the stimulus was significant in guiding its eventual response to the stimulus itself. Given the arguments of James and his successors, it seems obvious that the state of the body, or the brain's response to that state, in 'hot' (emotionally valenced) cognition might have substantial effects on perception and action, and such effects have been elegantly demonstrated<sup>11,12</sup>. But it is less immediately apparent why bodily states (or the brain's interpretation of such states) should have such a marked effect on the apparently arbitrary visual perception task chosen by Park *et al.*<sup>3</sup>. The authors speculate that successful detection depends on an enhanced subjective feeling of the self at the time of the stimulus that might be provided by the enhanced neural responses to pre-stimulus heartbeats that they observed. This is reminiscent of theories of consciousness that emphasize embodiment as a precursor to the experience of subjective states<sup>14</sup>.

There are other possible interpretations of these striking results. For example, although the authors measured many bodily parameters, it is impossible in principle to rule out the possibility that there might be some difference in the physiology of those heartbeats (or associated with those heartbeats) that preceded correct detections rather than misses. This alternative is important, as it implies that the critical difference in cerebral responses to heartbeats that precede the stimulus might not be spontaneous, but is instead a reflection of an interaction between the stimulus and some aspect of the body's state. For example, one theoretical possibility is that weaker than expected heartbeats might provoke greater heartbeat-evoked responses, but allow more sensitive performance at visual detection as a result of reduced physical motion of the body or the less distracting effects of such beats. Detecting such physical effects may be challenging and would require more invasive measures.

Are the findings reported by Park *et al.*<sup>3</sup> relevant to the observation that the heartbeat is tracked over wide areas of cortex<sup>2</sup>? It is tempting to speculate that they might be; if information about the heartbeat is relevant to the psychophysically pure, but fundamentally humdrum, visual grating detection task performed by the participants in this study, it may turn out to be important in many other domains of perception and action. On the other hand, it is interesting that the critical differences in heartbeat-evoked responses identified by Park *et al.*<sup>3</sup> localized to brain regions not conventionally recognized as showing task-relevant activity during visual detection. Instead, these differences were seen in areas more frequently associated with 'default mode' activity<sup>15</sup>

(Fig. 1), so perhaps these regions will ultimately be shown to integrate viscerally related responses into performance on a variety of tasks.

Whatever the precise explanation and interpretation, these findings make a substantial contribution to the decades-old debate over the meaning of spontaneous activity: they suggest that at least some aspects of such activity are best regarded not as spontaneous but as differential responses to visceral states. It seems that, although the seat of sensation is not the heart (as Aristotle supposed), it might reasonably be argued that, in the light of this evidence, it is a crucial component of the source. Given how seriously the brain appears to be taking the heartbeat, perhaps we as experimenters need to do so as well.

#### COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

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## So many progenitors, so little myelin

Steven A Goldman & Joana Osorio

**CNS white matter injury may cause sustained demyelination despite the persistence of oligodendrocyte progenitor cells (OPCs). A study suggests that dysregulated Wnt signaling disrupts self-renewal to yield OPC maturation arrest.**

Demyelinating injuries, as seen in multiple sclerosis, white matter stroke and many forms of cerebral palsy, are generally characterized

by limited remyelination, and recurrent episodes of demyelination are especially bereft of recovery potential. Yet these same myelin-deficient foci often retain ample numbers of precursor cells with the potential to become myelinating cells, namely oligodendrocyte-astrocyte glial progenitor cells (OPCs), and seemingly arrested premyelinogenic oligodendroglia<sup>1–3</sup>. This paradoxical failure in

remyelination despite the persistence of available progenitors has been the focus of recent research as part of a broader effort to improve remyelination competence. Although studies have made headway toward identifying triggers for oligodendrocyte differentiation and myelination from endogenous progenitors<sup>4,5</sup>, none have cracked the fundamental problem of why the injury environment is so often

Steven A. Goldman and Joana Osorio are in the Center for Translational Neuromedicine and the Department of Neurology of the University of Rochester Medical Center, Rochester, New York, USA. e-mail: [steven\\_goldman@urmc.rochester.edu](mailto:steven_goldman@urmc.rochester.edu)