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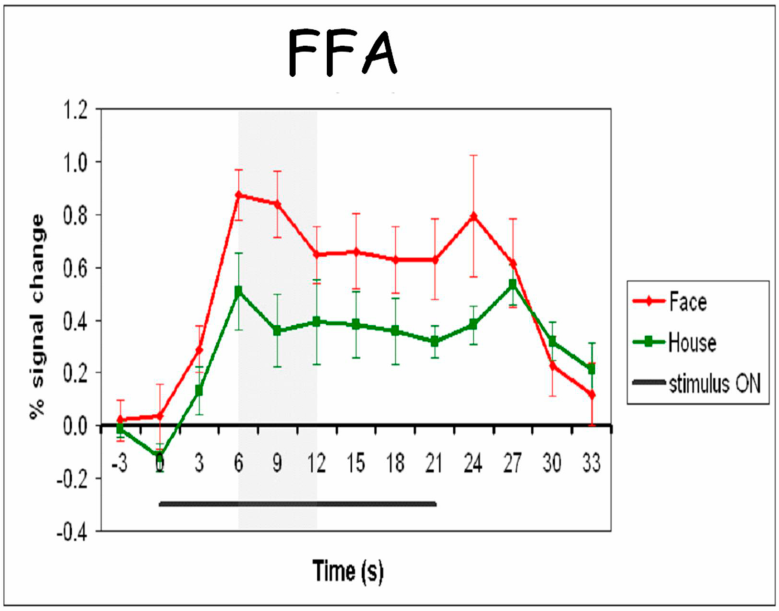
Neuronal Explosions: Neuronal dynamics underlying perceptual awareness in the human cerebral cortex

Despite many years of intensive research, the neuronal mechanisms that give rise to conscious perception remain elusive. We have previously argued that the search for such neuronal processes should be focused on local activity within the visual system itself rather than more global spread to self-related pre-frontal areas (Goldberg et al 2006, Golland et al 2007, Malach 2007)- but it is far from being established what type of neuronal activity in such local circuits is necessary and sufficient to elicit a conscious percept.

A number of brain imaging results from our group and others point to high levels of fMRI signal as a likely candidate for conscious perception. When object and face images are presented at the threshold of detection, we find a highly non linear increase in fMRI signals in ventral-stream object areas which is tightly correlated to the perceptual experience rather than the physical aspects of the stimulus (Grill-Spector et al 2000) see also (Quiroga et al 2008). Similarly, in the case of ambiguous figures such as the famous Rubin vase-face illusion, high fMRI activity in face-related regions correlates with the dynamic emerging percept of a face- again in a condition where the optical stimulus is unchanged (Hasson et al 2001). Thus, a plausible hypothesis summarizing these results is that non linear increases in neuronal activity- "neuronal explosions"- is the mechanism underlying the emergence of a percept in the observer's mind.

However, these consistent fMRI findings are only a first step in experimentally verifying this hypothesis. An important question relates to the fMRI signal itself- since it has been extensively debated to what extent fMRI signals actually reflect the firing rates of cortical neurons. In a number of recent studies, we have shown that in human sensory cortex, this is indeed the case- ie the fMRI measures the averaged activity of a large neuronal population of ~3mm in size (Mukamel et al 2005, Nir et al 2007a).

A second major issue concerns the phenomena of fMR-adaptation (also termed repetition-suppression). We and others have demonstrated that repeated presentation of the same object image leads to consistent reduction in the fMRI signal (Grill-Spector & Malach 2001). This phenomenon appears, at a first glance, to be directly in contrast to the "neuronal explosions" model- since it shows that perception may persist even when neuronal activity declines. To examine whether this is indeed the case- we conducted an extreme version of the adaptation paradigm, where a single unchanging visual image was presented for many seconds. Our results (Gilaie-Dotan et al 2008), Figure 1) show that following a short transient, the activity in high order object recognition areas remained sustained throughout the time of perceptual experience- in line with the notion that this activity is the neural correlate of the percept itself.

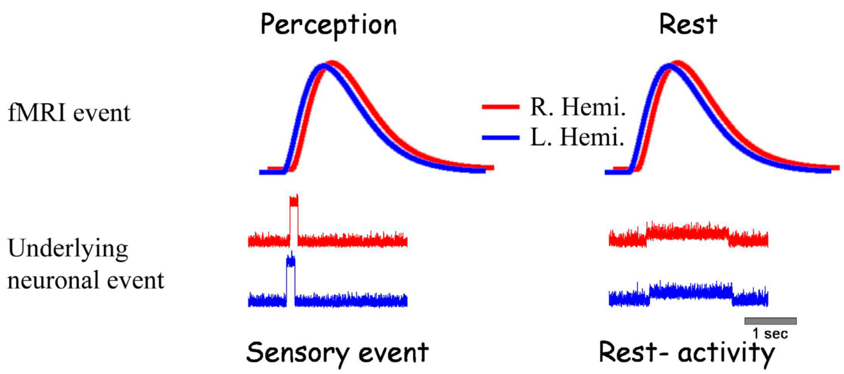


fMRI response to a single, sustained, visual image
Signal from face-related high order visual area in response to a single face or building image presented for 20 seconds. Note that the signal remains significantly above baseline throughout the perceptual state

More recently, we have examined the "neuronal explosions" model from a completely different angle- contrasting evoked with spontaneous rest activity.

In the fMRI field, recent research have focused a lot of attention on the behavior of the visual system when no sensory stimulus or experience is elicited. It turns out that large fMRI waves are consistently present during such rest periods ((Nir et al 2006). Again, it may appear that such waves completely refute the notion of neuronal explosions- if such high fMRI activity is present in sensory cortex, how come it does not elicit hallucinatory perceptual events in correspondence with the high amplitude waves of spontaneous fMRI activity?

In fact, the spontaneous waves offer an excellent opportunity to examine in detail the dynamic signatures that differentiate neuronal activity associated with perceptual events from that associated with non-perceptual spontaneous activity. Note that the fMRI is a slow marker of neuronal



Differential neuronal dynamics associated with perception and rest activity
Schematic summary of neuronal activity associated with auditory stimulation (left) and quiet rest (right)- note that auditory perception is associated with high amplitude bursts of activity as opposed to the low-amplitude rest activity, although both elicit high amplitude fMRI waves.

activity. Thus, a large fMRI wave can be generated either by slow, low-amplitude waves or by a fast "explosive" increases in firing rate. In collaboration with prof. I. Fried and a prominent group from the Tel Aviv Medical center (S Kipervasser, F Andelman, M Y. Neufeld, U Kramer, see (Nir et al 2007b) we have now dissected out the neuronal dynamics of the different states. Our results are summarized in the schematic model above (Figure 2). Sensory-related activity is characterized by rapid and short duration bursts of high neuronal firing (see also (Bitterman et al 2008)), while rest activity, which does not elicit any sensory percept is characterized by very slow, low amplitude neuronal activity.

To summarize, a number of lines of recent evidence converge in supporting the notion that the neuronal processes that give rise to perceptual experience are high firing- "explosions" of neuronal activity in high order sensory areas.

Selected publications

Bitterman, Y., Mukamel, R., Malach, R., Fried, I. and Nelken, I. (2008) Ultra-fine frequency tuning revealed in single neurons of human auditory cortex. Nature, 451, 197-U199.

Gilaie-Dotan, S., Nir, Y. and Malach, R. (2008) Regionally-specific adaptation dynamics in human object areas. Neuroimage, 39, 1926-1937.

Goldberg, II, Harel, M. and Malach, R. (2006) When the brain loses its self: Prefrontal inactivation during sensorimotor processing. Neuron, 50, 329-339.

Golland, Y., Bentin, S., Gelbard, H., Benjamini, Y., Heller, R., Nir, Y., Hasson, U. and Malach, R. (2007) Extrinsic and intrinsic systems in the posterior cortex of the human brain revealed during natural sensory stimulation. Cerebral Cortex, 17, 766-777.

Grill-Spector, K., Kushnir, T., Hendler, T. and Malach, R. (2000) The dynamics of object-selective activation correlate with recognition performance in humans. Nature Neuroscience, 3, 837-843.

Grill-Spector, K. and Malach, R. (2001) fMR-adaptation: a tool for studying the functional properties of human cortical neurons. Acta Psychologica, 107, 293-321.

Hasson, U., Hendler, T., Ben Bashat, D. and Malach, R. (2001) Vase or face? A neural correlate of shape-selective grouping processes in the human brain. Journal of Cognitive Neuroscience, 13, 744-753.

Malach, R. (2007) The measurement problem in human consciousness research. Behavioral Brain Science, 30, 481-499.

Mukamel, R., Gelbard, H., Arieli, A., Hasson, U., Fried, I. and Malach, R. (2005) Coupling between neuronal firing, field potentials, and fMR1 in human auditory cortex. Science, 309, 951-954.

Nir, Y., Fisch, L., Mukamel, R., Gelbard-Sagiv, H., Arieli, A., Fried, I. and Malach, R. (2007a) Coupling between neuronal firing rate, gamma LFP, and BOLD fMRI is related to interneuronal correlations. Current Biology, 17, 1275-1285.

Nir, Y., Fisch, L., Mukamel, R., Gelbard-Sagiv, H., Arieli, A., Fried, I. and Malach, R. (2007b) Slow coherent modulations of spontaneous neuronal activity in human auditory cortex: implications for spontaneous fMRI. Society for Neuroscience, Vol. 613.1.

Nir, Y., Hasson, U., Levy, I., Yeshurun, Y. and Malach, R. (2006) Widespread functional connectivity and fMR1 fluctuations in human visual cortex in the absence of visual stimulation. Neuroimage, 30, 1313-1324.

Quiroga, R.Q., Mukamel, R., Isham, E.A., Malach, R. and Fried, I. (2008) Human single-neuron responses at the threshold of conscious recognition. Proceedings Of The National Academy Of Sciences Of The United States Of America, 105, 3599-3604.

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