The mind-body problem: neurophysiology of looking and seeing

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The mind-body problem. When you intend to move your finger, what actually moves your finger? You experience your *intention*, but does it exist in the same sense as your body? Probably not: your finger, your body, is part of material reality—objective, observable by all. In contrast, your *intention*, your mind, is subjective, private by definition—apparently, not part of material reality. Thus, everybody can observe whether your finger moves but only you can tell if you have had the *intention* to move it. The body and mind are so different from each other that it seems impossible for them to interact. So, could your *intention* cause your body to move?

Past and future. The mind-body problem has been with humankind since the beginning of civilization (for example, see quotes in Fig 1). Could there be any hope for making significant advances on such an ancient problem? I believe that our perspective on mind-body is going to change, drastically, and soon. This change is being brought about by the recent explosive development of neuroscience. Although abstract, the mind-body problem depends on concepts and assumptions that emerge from our experiences with brains and minds. The database of mind-body experiences is now rapidly expanding. In the last few decades we have become aware of brain states, even states of single neurons, which appear to faithfully reflect subjective, private mental processes, such as intentions (Fig 2). What does this suggest for the future of the mind-brain problem? I believe the answer is: the actual questions that make up the mind-body problem will be modified. The new questions will relate to the brain's functional architecture much more closely (manuscript in preparation).

The experimental system we use to probe mind-body relates to the sense of vision and to eye movements of a specific type, called saccades.

Sensation and perception. Vision begins with the sensation of photons hitting receptors in the retina, and ends with visual perception. The relationship of our percepts to 'what is out there' is highly indirect, selective and context-contingent. Context-based interpretation and selective attention are crucial for perception: we are usually aware of only a small fraction of the information present in the world around us.

The need for eye movements. High-acuity vision is captured only in a very small spot at the center of our retina ('fovea'). To capture more than one small part of the visual scene, we *must* shift the fovea to the interesting, informative locations in the scene. Consequently, while looking, our eyes remain quite stationary for a fraction of a second at one location of a scene ('fixation'), and then, very rapidly, jump to another location, ('saccade'). The fixation-saccade cycle goes on and on, at a rate of several saccades per second.

Saccadic eye movements are crucial for vision. Saccades result from complex evaluations of potential targets culminating in the selection of a target. Demanding sensorimotor transformations lead to construction of specific motor plans. Saccades, and trans-saccadic visual processing, require working memory and further complex processing. A network of brain areas, including highest-order areas in the cerebral cortex, is involved in saccades.

Strategically positioned between sensation, perception, motor plans and decisions, saccades make a fine model for studying the interface of mind and brain.

Neurons are the atoms of information-processing in the brain. Two fundamental properties turn neurons into 'atoms' of information-processing:

- Information flow across the neuron is *directed*, flowing from input synapses on the dendritic tree to output synapses made by the axonal arborizations.
- The neuron's *sole* output is a series of pulses ('spikes'), sent out in parallel to all the neuron's thousands of output synapses.

Thus, the 'next' neuron is oblivious to intracellular elements of information processing. All it has access to is the series of spikes that the neuron generates.

וַיִּבְרָא אֱלֹהִים אֶת-הָאָדָם בְּצַלְמוֹ, בְּצֶלֶם אֱלֹהִים בָּרָא אֹתוֹ (בראשית א׳ כ״ז)

...עָפָר אַתָּה, וְאֶל-עָפָר תָּשׁוּב. (בראשית ג׳ י״ט)

God created man in his own image, in the image of God created he him... (Genesis 1:27)

...dust thou art, and unto dust shalt thou return. (Genesis 3:19)

Fig. 1

Neurons are elements of circuits and assemblies. These circuits are not like chemical molecules, which hide individual properties of constituent atoms. Rather, the circuits appear to recapitulate on the properties of their single neurons.

Thus, understanding the response properties of single neurons is crucial for understanding representation and processing of information by the brain. A weakness of imaging methods, such as fMRI, is that they do not allow access to the level of single neurons.

Brain science is interdisciplinary, and so is our approach. I believe in the promise, indeed, necessity, of multidisciplinary approaches to the brain. Indeed:

- *Physiology* is our bread and butter, and
- *Anatomy* is the a-b-c of brain science. Without anatomy there is no sense for physiology.

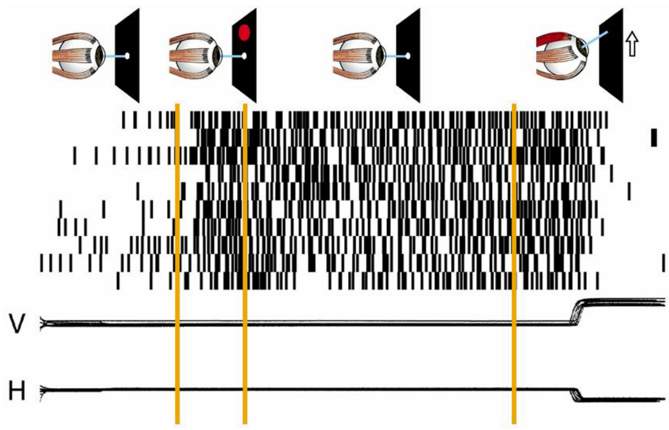

Fig. 2 *Typical data in our experiments: activity (spikes) of a single cortical neuron that might reflect the subject's* intention *to make a saccade upward and a little to the left. The figure shows, at top, the behavioral paradigm: while the subject fixates a central spot a target is briefly flashed in a peripheral location. Only after the central spot goes off the subject is allowed to move the eyes; this movement is required to be a saccade toward the location in which the target was previously flashed. The raster shows the spikes in 10 trials: each notch stands for a spike, each line stands for a trial. These trials were mixed with other trials in which the target appeared elsewhere. V and H show the vertical and horizontal eye position records. The neuron's spike rate increases shortly after the target appears in this specific location; the high rate persists throughout the memory interval until the saccade, then returns to baseline. Persistent activity is usually associated with working memory; additional studies indicated that this memory reflects the plan to make the next saccade.*

- *Psychology:* most of what we do might qualify as a special type of cognitive psychology;
- *Philosophy:* significant for experimental design and discussions;
- *Molecular biology:* promises synergism, combined with neurophysiology. We are starting collaborations (see below).
- *Neurology and psychiatry:* we have ongoing collaborations on several disorders, with particular interest in schizophrenia. Here, our basic research makes an impact on clinical science.
- *Computers and math:* I believe the computer metaphor still has a lot to teach us about the brain. I am particularly interested in brain analogs of operating systems—that are illuminating for cognitive psychology subjects, such as task switching. I also have a long-standing interest in geometry as a constructive theory of perception (manuscript in preparation).

Some examples of specific issues that we are studying

Example 1. The structure of intentions: relationship of parietal and prefrontal areas.
Fig. 2 illustrates the activity of one parietal neuron that reflects the motor plan to look to a specific region of space (the neuron's 'response field'). This type of activity is present in areas throughout cerebral cortex. We are running experiments, both basic and in patients, to understand the structure and dynamics of the inter-areal activity, and the relations of the intentions to the evolving visual perception.

Example 2. Free choice. The representation of plans for action naturally generalizes to study of choice, reflected as competition between the represented plans. We study free choices—both choices that reflect preferences, and choices that are made between seemingly equivalent plans.

Example 3. Social cognition. Eye movements are important for interpersonal communication. We try to understand the activity in the same system of cortical areas when attention and saccades are driven by social context.

Example 4. Nicotinic and dopaminergic control states. We are collaborating with molecular biology groups on the significance of these systems and their interactions to intentions and choices.

Selected publications

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Acknowledgements

Current support: Joint BMBF-MOST German-Israeli Research Program, VW Foundation, and ISF.