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Bridging body and mind: Neuronal signals, eye movements, brain architectures

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The fundamental problem driving our research is that of understanding the relationship of body and mind. Our bodies are part of physical reality, objective, open to all. Our minds are subjective, private. How can the two fit together?

The diagram on the left of Fig 1 illustrates the flow of information between body and mind. Light from the external world excites sensory cells in our retinas, which send the information to the brain. Based on these messages, perceptions of the external world are formed in our minds. Subsequently, intentions to act in the external world are formed as well. Intentions are subjective, private; only if actuated they become behavior, objective, part of physical reality. The simplest intentions are plans for movement. Based on our intentions, the brain sends motor commands to the muscles, which act on the external world.

The blue arrows and the red arrows make up the sensorimotor loop in which we spend our lives. The blue arrows, of sensations, are translated into the red arrows, of motor commands, by 'sensorimotor transformations'. The red arrows are translated into blue arrows less directly; however, the influence of our movements on our subsequent sensations is the essence of 'active vision', a subject of intensive current research.

We understand now the workings of the eyes and the muscles quite well. Much is known also about the first stages of processing of sensation and motor commands, that is, the lower parts of the blue and red arrows. The further up one goes into issues which are neither sensory nor motor, the less is at present understood. Between the sensory and motor territories lie issues such as decisions, problem solving, and the effect of global, contextual understanding on our actions. These and other questions are now being addressed. Because they are remote from external stimuli and behavior, a challenge is to define them carefully and study them without compromising scientific rigor.

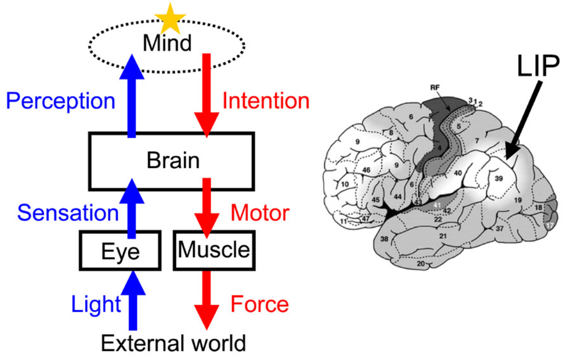

Fig. 1 *Left, scheme of sensory-motor processing; right, an image of the brain (processed from Fuster, Neuron 2001) illustrating the procession from primary sensory and motor areas (dark gray) to secondary areas (light gray) and into association cortex (white).*

The diagram of the brain at the right shows a cartoon of the cerebral cortex. The primary sensory and motor areas, the input and output areas of the cortex, are marked in dark gray. They make up only a small portion of the cortex. The light gray regions reflect cortex primarily related to one sense or to movement, though reflecting higher levels of processing. The area in white is 'association cortex', less obviously linked to either sensation or movement. We have been studying regions of association cortex, mainly the lateral intra-parietal area (abbreviated LIP), shown on the diagram. Area LIP is an area of association cortex that is related to saccadic eye movements.

The system we study is that of the control of looking. Figure 2 illustrates a typical experiment. We train monkey subjects on the task illustrated by the cartoons at the top of the figure (called 'memory-saccade'). The subject must continuously look at a white spot ('fixation spot') that comes on at the center of a dark screen; the trial is immediately aborted if the eye moves away from the fixation spot. After an initial 0.5s fixation interval, another, peripheral spot ('target') comes on, and after another 0.25s the target goes off. The fixation spot is sustained for another 1s after the target goes off. During this 'memory interval' the subject must remember where the target was displayed and, and must form a motor intention to look at the remembered location, because when the memory interval ends, with the fixation spot eventually going off, the subject must saccade to the screen location where the target had previously appeared.

The lines marked V and H show that the monkey performs the task appropriately. These are traces of the vertical and horizontal components of the eye position. While the fixation spot is on, the eyes are stationary. After the fixation spot goes off, a single saccade shifts the eyes to the appropriate, remembered position on the screen.

Figure 2 illustrates the activity of one neuron of area LIP while a subject performs memory-saccades. Each horizontal line represents one trial, each small vertical line a single spike. In all trials, the target's appearance is followed, within less than 0.1s, by a rapid, vigorous increase in spike rate. The elevated spike rate persists until the saccade is made. Shortly after the end of the saccade the activity stops.

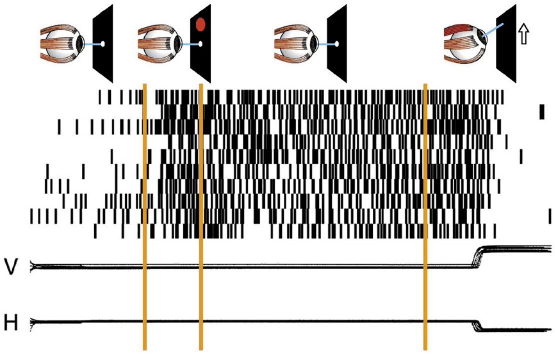

Fig. 2 *The memory-saccade task (top) and illustration of the activity of a single LIP neuron while the task is performed. The activity reflects working memory, a combination of visual memory of the target's image and motor intention, the plan to rotate the eye so as to turn the line of sight to the previous position of the target.*

The persistent activity clearly reflects a form of "working memory". Memory for what? Visual memory of the target's image, or memory of the plan to make a saccade? We found that the persistent activity is a combination of both types of memories. Using a similar task, in which the subjects had to look to the direction opposite that of the peripheral stimulus, we showed that the total LIP persistent activity shifts from the visual direction to the motor, thereby reflecting the time-course of the sensorimotor transformation.

We are currently using these techniques to address questions of free choice. Imagine you have to look at one of two identical peripheral spots, on either side of your line of sight. How do you decide at which target to look? We study brain activity that reflects the subject's decision. Remarkably, when subjects undertake free choice, their persistent LIP neuronal activity goes into a very specific pattern of activity.

Selected Publications

Barash, S., Melikyan, A., Sivakov, A., zhang, M., Glickstein, M., and Thier, P. (1999) Saccadic dysmetria and adaptation after lesions of the cerebellar cortex. J. Neurosc., 19, 10931-9.

Thier, P., Dicke, P.W., Haas, R., and Barash, S. (2000) Encoding of movement time by populations of cerebellar Purkinje cells. Nature, 405, 72-6.

Zhang, M., and Barash, S. (2000) Neuronal switching of sensorimotor transformations for antisaccades. Nature, 408, 971-5.

Barash, S. (2003) Paradoxical activities: insight into the relationship of parietal and prefrontal cortices. Trends in Neurosci., 26, 582-9.

Zhang, M., and Barash, S. (2004) Persistent LIP activity in memory antisaccades: working memory for a sensorimotor transformation. J. Neurophysiol., 91, 1424-41.

Barash, S., Wang, X., Zhang, M., Tauber, M., and Melikyan, A. (in process). Free-choice memory-saccades: asymmetrical cortical representation.

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