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Separate Cognitive and Motor Maps in Vision

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Abstract

Several topographic maps represent the visual world in the cortex. This characteristic of the visual system raises a question for visual physiology: do all of these maps work together to create a single representation of visual space, or are they functionally distinct? If they are distinct, how many functional maps are there, what does each one do, and how do they communicate with one another? This paper presents psychophysical evidence for at least two functionally distinct representations of the visual world in normal humans; under some conditions, the two representations can simultaneously hold different spatial values. The paper also demonstrates some of the ways in which the representations communicate with one another.

The normal human possesses two maps of visual space. One of them holds information used in perception: if a subject is asked what he or she sees, the information in this 'cognitive' map is accessed. This map can achieve great sensitivity to small motions or translations of objects in the visual world by using relative motion or position as a cue. The price that the cognitive system pays for gaining this sensitivity is that it loses absolute egocentric calibration of visual space. A useful model for this process is the process of differentiation in calculus. In calculating motion dx/dt by differentiation, the constant term (the spatial calibration) drops out of the representation.

The other visual map drives visually guided behavior, but its contents are not necessarily available to perception. This map does not have the resolution and sensitivity to fine-grained spatial relationships that the cognitive map has, but it is not required to: a small error in pointing, grasping or looking is of little consequence. The advantage of this map is its robustness; the "motor" map is not subject to illusions such as induced motion.

Studies of saccadic suppression and induced motion suggest separate representations of visual space for perception and visually guided behavior. Because these methods require stimulus motion, subjects might confound motion and position signals. We separate cognitive and sensorimotor maps without motion of target, background, or eye, with an 'induced Roelofs effect': a target inside an off-center frame appears biased opposite the direction of the frame. A frame displayed to the left of a subject's centerline, for example, will make a target inside the frame appear further to the right than its actual position. The effect always influences perception, but in half of our subjects it does not influence pointing.

Cognitive and sensorimotor maps interact if the motor response is delayed; all subjects now show a Roelofs effect for pointing, suggesting that the motor system is being fed from the biased cognitive map. A second experiment showed similar results when subjects made an open-ended cognitive response instead of a 5-alternative forced choice. Experiment 3 showed that the results were not due to shifts in subjects' perception of the felt straight ahead position. In experiment 4, subjects pointed to the target and judged its location on the same trial. Both measures showed a Roelofs effect, indicating that each trial was treated as a single event and that the cognitive representation was accessed to localize this event in both response modes.

In more recent experiments we have made a subtle but important change in the motor task: instead of indicating with the finger to the experimenter where the target is located, the subject simply jabs it with the forefinger, knocking over a peg. The movement is almost identical, but the movement's function is instrumental rather than communicatory. This yields a cleaner dissociation between cognitive and motor representations, and shows that the motor system's memory for position lasts 2 seconds or less.

Another way of interpreting the relationship between cognitive and motor representations of visual space is in terms of the ability to integrate information from the map with other information. The cognitive map's contents are coded in terms of the entire visual array (both target and frame in our case), while the motor map is generally inaccessible to integration with information from other sources. The difference between cognitive and motor representations in this context is analogous to the distinction between explicit and implicit modes of memory, respectively. The explicit mode is accessible to language and to experiential memory, while the implicit mode may hold information that the subject is unaware of or even that is contradictory to other explicit memory. Similarly, in our experiments subjects can hold one position of a stimulus in the cognitive representation and simultaneously hold a different position for the same stimulus in the motor representation.