Up to now, research on visual cortical microstimulation in humans has focused on the induction of phosphenes—percepts of point-like luminosity induced by electrical shock. Early studies in V1 produced these phosphenes individually and occasionally in small groups; researchers have since tried to develop large electrode arrays capable of heavily parallel current distribution. The underlying assumption is that a multitude of phosphenes created simultaneously might convey to the subject a percept of some shape—say, a letter or a doorway.

An argument against the strict application of this approach is that visual cortex does not really work this way—by assembling points. Instead, V1 neurons respond to specific image properties such as orientation, direction of motion, and binocular disparity, and they collectively represent a multidimensional map of the visual world. Our visual percepts stem from activity patterns defined in this multidimensional tuning space, not in terms of a simple x-y positional grid.

The complexity of visual processing necessitates a systematic and informed approach to interfacing and communicating with the cortex. The present work contributes in this regard by establishing basic protocols and paradigms for behavioral testing of cortical arrays in monkeys.

One hundred ninety-two intracortical electrodes were implanted in the right V1 of a rhesus monkey. All were made of parylene-C coated, activated iridium and were designed for both stimulating (current delivery) and recording (voltage sampling). 128 electrodes had 500 μm^2 exposed tips and were contained in 8-wire clusters; the other 64 had 200 μm^2 tips and were in groups of 1 or 2. Thirty-five were destroyed before or during the implantation surgery; among the remaining 157, 117 had impedance appropriate for stimulation.

In initial tests, we measured each electrode's effective receptive field; that is, the combined field of neurons sampled at the tips (generally 5-10). In 62 neurons a precise field was mapped to ~0.5° resolution. Probably a number of fields were missed because initial mapping was done over a limited (10°×10°) area. For all mapped fields, we then tested for orientation and direction tuning using 1-dimensional moving random lines. Preliminary results suggest that the majority of fields show both orientation and direction selectivity. Recall that the field in question is the effective receptive field for a given electrode; thus the tuning described above refers to the collective behavior of a small neural ensemble.

Prior to electrode implantation, the monkey had been trained in a memory saccade task. He was required to fixate while a point flashed in the left visual field, hold fixation for another 500 msec, then look to the remembered flash location. After implantation, his task was switched to an electrical version in which the visual flash was replaced by a 1 second current delivered through one of the electrodes (100 Hz, typically 25-35 μA, biphasic). He was required to hold fixation for 500 msec after current cessation, then look to the remembered "flash" (phospene) location. A memory (vs. direct) saccade task was

used to prevent eye movements during stimulation, in which case phosphenes appear to move.

Knowing the effective receptive field for each electrode, we rewarded the monkey when his saccade landed within a certain distance from this field, since this was the presumed location of the (presumed) phosphene. Initially the distance was ~4° and gradually decreased to 1.5°.

Approximately 2 weeks were required before the monkey showed an obvious tendency to saccade to phosphenes. Unfortunately, eye position data for this period were lost; however, within 4 weeks the data clearly showed the clustering of saccade endpoints on roughly half the channels. For all electrodes combined, there was a significant correlation between the x and y location of the saccade endpoint and the location of the stimulated receptive field ($p<0.05$).

These findings suggest that behaving primate experiments will contribute substantially to the development of cortical visual prostheses. Our tests have already indicated improvements in surgical procedure and electrode construction techniques, as well as better methods for training animals; but more importantly, we can now begin to test the effectiveness of different stimulation strategies. We have recently begun tests to measure saccade endpoint accuracy as a function of current amplitude, frequency and pulse width, as well as the random vs. periodic distribution of stimulation pulses in time. In future experiments we also plan to train animals in a orientation- and direction- judgment tasks and explore the optimal combination of inputs over space and time in terms of eliciting specific behavioral responses.