

Journal Club

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Two's a Crowd: Suppressed V4 Visual Responses to Sequential Stimuli

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Review of Motter (<http://www.jneurosci.org/cgi/content/full/26/38/9683>)

Every minute, we sweep our eyes over multiple objects. We look at one object and then another, shifting our gaze across cluttered scenes when, for example, searching a desktop for car keys. Such real world complexities are difficult to model in the laboratory. Instead, a single stimulus is often used to characterize visual responses of neurons, be it a small bar in primary visual cortex (V1) or a three-dimensional object in “higher” cortical areas in the inferotemporal (IT) and frontal lobes. Forays into more complex tasks using multiple stimuli have mainly been limited to simultaneously presented stimuli in search and visual clutter tasks. Remarkably few studies have investigated how visual cortices respond to sequential stimulus presentations. This paucity of research is surprising given the wealth of data collected in the psychophysical literature regarding the temporal phenomena of visual masking and inhibition of return. A recent paper in the *Journal of Neuroscience* (Motter, 2006) begins to fill this conceptual void. The author recorded from visual area V4 in awake behaving monkeys while long sequences of stimuli were presented.

The author first investigated the visual responses of V4 cells to sequences of task-irrelevant identical stimuli. Monkeys fixated a spot while six to eight letter-like stimuli were flashed in the receptive field [Motter (2006), his Fig. 1 (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F1>)]. Importantly, Motter selected a stimulus duration (200 ms) and inter-stimulus intervals (ISIs) that mimicked the timing of retinal stimulation associated with rapid eye movements. Sequences using short ISIs (55 and 110 ms) were akin to the stimulation and blanking experienced before, during, and after an eye movement. Previous studies of neuronal habituation in visual cortices, from V1 to IT, suggested that the second visual response would be diminished (Baylis and Rolls, 1987; Müller et al., 1999). What about the later stimuli in the sequences? They could continue to decrease with repeated stimulus presentation (Fig. 1A, top) or remain at the low, plateaued level (Fig. 1A, bottom). In terms of timing, they could remain locked to stimulus onset (Fig. 1B, top) or “wax and wane” because of poorly understood feedback mechanisms (Fig. 1B, bottom)

Motter (2006) demonstrated a robust habituation to sequences of identical stimuli. After the initial stimulus presentation, neuronal responses diminished and remained so for the duration of the sequence. The sustained component of the first response decreased quickly and remained at the level of the second response, whereas the transient component

continued to decline as ISI decreased [Motter (2006), his Fig. 4 (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F4>)]. Perhaps unsurprisingly, at the 55 and 110 ms ISIs, there was a concomitant increase in V4 activity between stimulus presentations as individual responses overlapped, preventing a return to baseline firing [Motter (2006), his Fig. 3 (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F3>)].

Also, neurons with predominantly transient responses showed decreased activity as ISI decreased, whereas predominantly sustained-component neurons remained conspicuously immune to such changes [Motter (2006), his Fig. 7 (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F7>)]. This disparity suggests a division of labor in neurons based on their endogenous firing characteristics, with highly transient-responsive neurons coding for repeated stimulus presentations. The function of the sustained group remained unclear, even after accounting for differences in baseline firing rate [Motter (2006), his Fig. 8D (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F8>)].

Neurons generally decreased their sensitivity to identical sequences [Motter (2006), his Fig. 8A, C (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F8>)]. However, V4 neurons showed an increased sensitivity to changes in identity [Motter (2006), his Fig. 9 (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F9>)]. Thus, predictable neuronal habituation was not the rule for mixed

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sequences, suggesting a putative mechanism for stimulus identity that operates in conjunction with the habituation of neuronal responses.

The author next analyzed the habituation–stimulus identity relationship with respect to stimulus history. Sequential position of the stimulus pair did not affect the subsequent response for either the transient or sustained subgroups of neurons [Motter (2006), his Fig. 10C (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F10>)]. Furthermore, preceding stimuli appeared to have no effect on neuronal responses in mixed sequences, but activity in identical sequences declined with successive presentations. Intriguingly, once stimulus tuning was taken into account, a correspondence between stimulus pair activity and color tuning category became clear [Motter (2006), his Fig. 11B (<http://www.jneurosci.org/cgi/content/full/26/38/9683/F11>)]. The majority of neurons that responded weakly to the secondary (“SE”) stimulus but showed large preferred (“PR”) activity were in the “tuned” category. We might think of these neurons as “waiting” for their particular preferred color to be presented and, until that time, responses remain relatively diminished. By comparison, other “broad” and “exclusion” neurons showed modest responses to both stimuli, with greater variability presumably stemming from the broader tuning curves of each neuron.

The identical and mixed sequences data suggest both intuitive and surprising conclusions. First, it is superficially trivial that the tuning properties of individual neurons dictated the responses to sequences of stimuli. Stimulus sensitivity curves (the mapping of neuronal responses to graded changes along a stimulus parameter) are integral to our understanding of visual cortical function. However, the dynamic relationship between the sensitivity of a given neuron and its moment-by-moment state of activity is opaque. Motter’s work clearly illustrates the primacy of stimulus tuning properties over continuous fluctuations in activity in response to repeated stimuli.

The author also suggests that the temporal similarity of the fixation paradigm to standard saccade and fixation intervals may allow for an extension of the results to more complex issues involving visual acuity surrounding eye movements. This approach is thought provoking, but it should be undertaken cautiously. Accumulating evidence shows that visual activity can change just before eye movements,

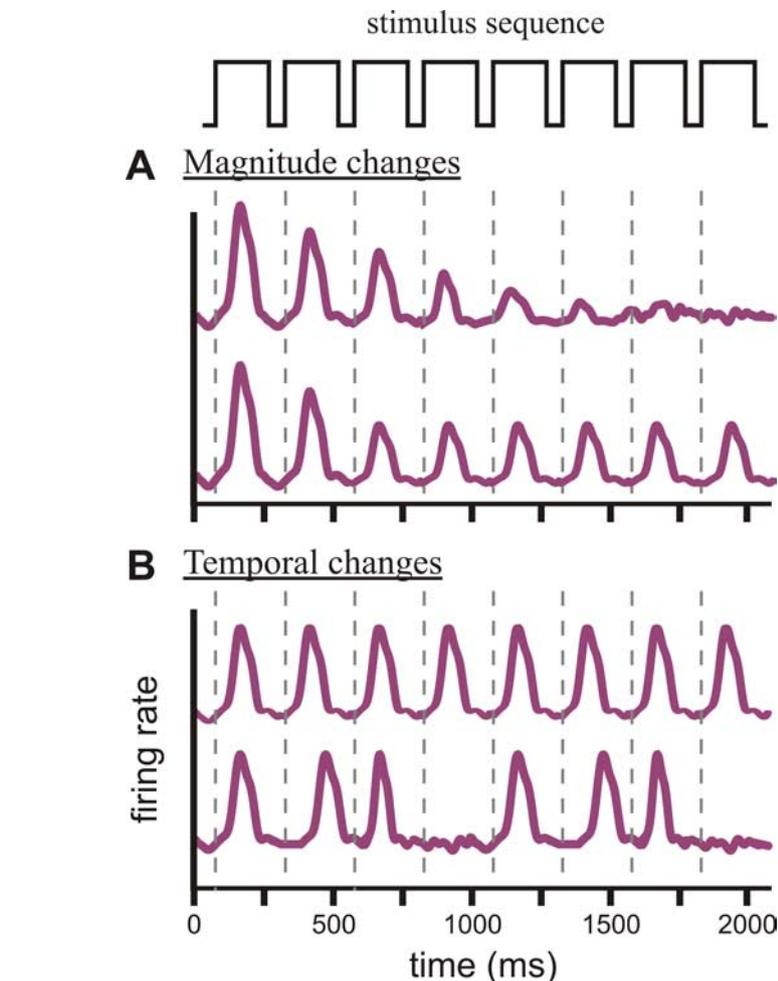


Figure 1. Changes in neuronal activity in response to a sequence of identical stimuli. Response trains are aligned to sequence onset. Dashed lines indicate individual stimulus onsets. **A**, Hypothetical effects on the magnitude of responses. The amount of activity continues to decrease over repeated stimulus presentations (top), or the responses initially decrease and then remain at a diminished level (bottom). **B**, Hypothetical effects on the timing of responses. Neuronal responses remain fixed in time relative to the stimulus onset (top), or overlapping responses lead to periods of “waxing” and “waning” attributable to potential oscillatory and feedback mechanisms (bottom). Simultaneous changes in both magnitude and timing are also possible (data not shown).

because of corollary discharge, in V4 and areas interlinked with it, such as lateral intraparietal area and frontal eye field (Duhamel et al., 1992; Tolias et al., 2001; Sommer and Wurtz, 2006). A temporally matched fixation task cannot completely model saccade conditions because the ability of the brain to predictively account for saccades is a critical component of perisaccadic visual activity. Notably, Motter’s findings are in no way limited by this caveat, because the responses to stimulus sequences are independent of the proposed fixation–saccade–fixation model. At the very least, this work provides clear answers to basic questions regarding neuronal responses to the visual bombardment experienced in our everyday world. Future studies may expand on this foundational work by focusing on controlled eye movements and recording from other visually responsive cortical areas.

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