# RELATIONSHIP OF RESPONSE LATENCY AND MAGNITUDE IN THE LGN OF MACAQUE MONKEY

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## INTRODUCTION

Response latencies of cortical neurons are not inexorably linked to response magnitude (Oram and Perrett 1992; Gawne et al 1996). The response latency of striate cortical neurons is heavily influenced by contrast whereas changes in response magnitude induced by changes in stimulus configuration (orientation) have relatively less effect on response latency. LGN neurons show increased response magnitude and decreased latency with increased stimulus contrast (e.g. Figure 1). We ask the question "Do stimulus contrast and stimulus configuration have separable effects on magnitude and latency in LGN neural responses?"

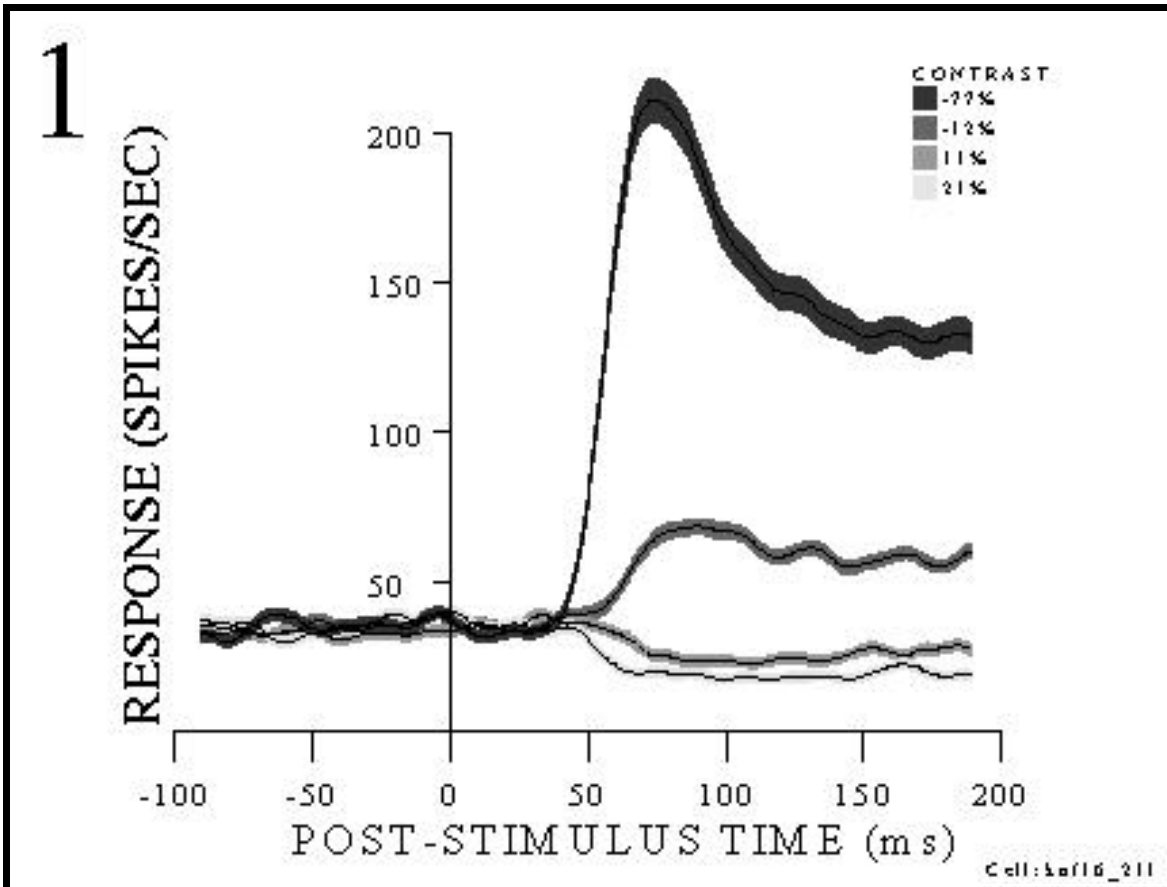


**Figure 1. Change in stimulus contrast produces change in both response magnitude and response latency.** The spike density function (± SEM) is shown for a single off-center cell (kof16_211) to stimuli of 4 contrast levels (-77%, -12%, 11% and 21%). The plots have not been adjusted for the delay in the display system for receptive field position: the actual response latency is some 10-16ms earlier than shown in this and subsequent plots. Reduction in the absolute value of contrast produces a reduction in the response measured as a deviation from the pre-stimulus onset activity. The latency of the response also co-varies with the neural response: the greater the response, the shorted the response latency. The aim of the study was to examine the dependency of response latency on stimulus contrast and response magnitude.

# METHODS

Single units were recorded from isolated LGN neurons of a fixating rhesus monkey. The neuron's receptive field was mapped by hand. Stimuli (Figure 2) were presented for 180ms periods in pseudo-random order centered on the neuron's receptive field. Trials in which the eye moved by more than 0.5 degrees were discarded.

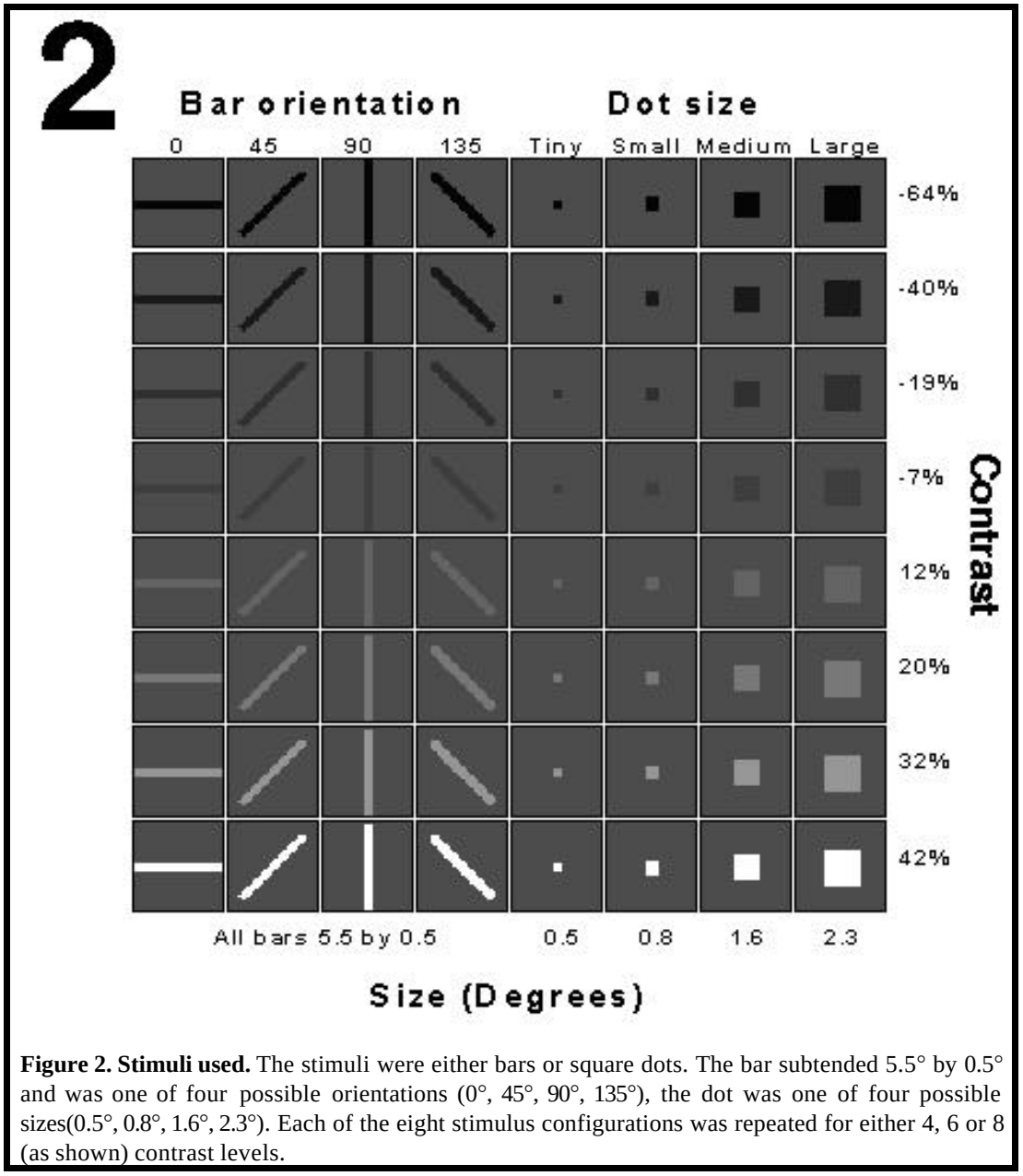


**Figure 2. Stimuli used.** The stimuli were either bars or square dots. The bar subtended 5.5° by 0.5° and was one of four possible orientations (0°, 45°, 90°, 135°), the dot was one of four possible sizes(0.5°, 0.8°, 1.6°, 2.3°). Each of the eight stimulus configurations was repeated for either 4, 6 or 8 (as shown) contrast levels.

Response magnitude elicited by each stimulus was assessed using spike count from 20 to 200 ms post-stimulus onset. 2-way ANOVA (contrast and stimulus configuration) was performed. Post-hoc testing was used to determine which stimulus configurations within each contrast level elicited statistically indistinguishable response magnitudes ($p > 0.05$). Responses were grouped across stimulus configuration according to magnitude and then

matched for magnitude across contrasts (Figure 3). This involved matching responses to effective stimuli at low contrasts with responses to less effective stimuli at high contrasts.

The spike trains were averaged and low-pass filtered with a 5 ms Gaussian to generate a spike density function. Response latency was assessed as the time when the spike density function first exceeded half of the peak of the density function (Gawne et al 1996).

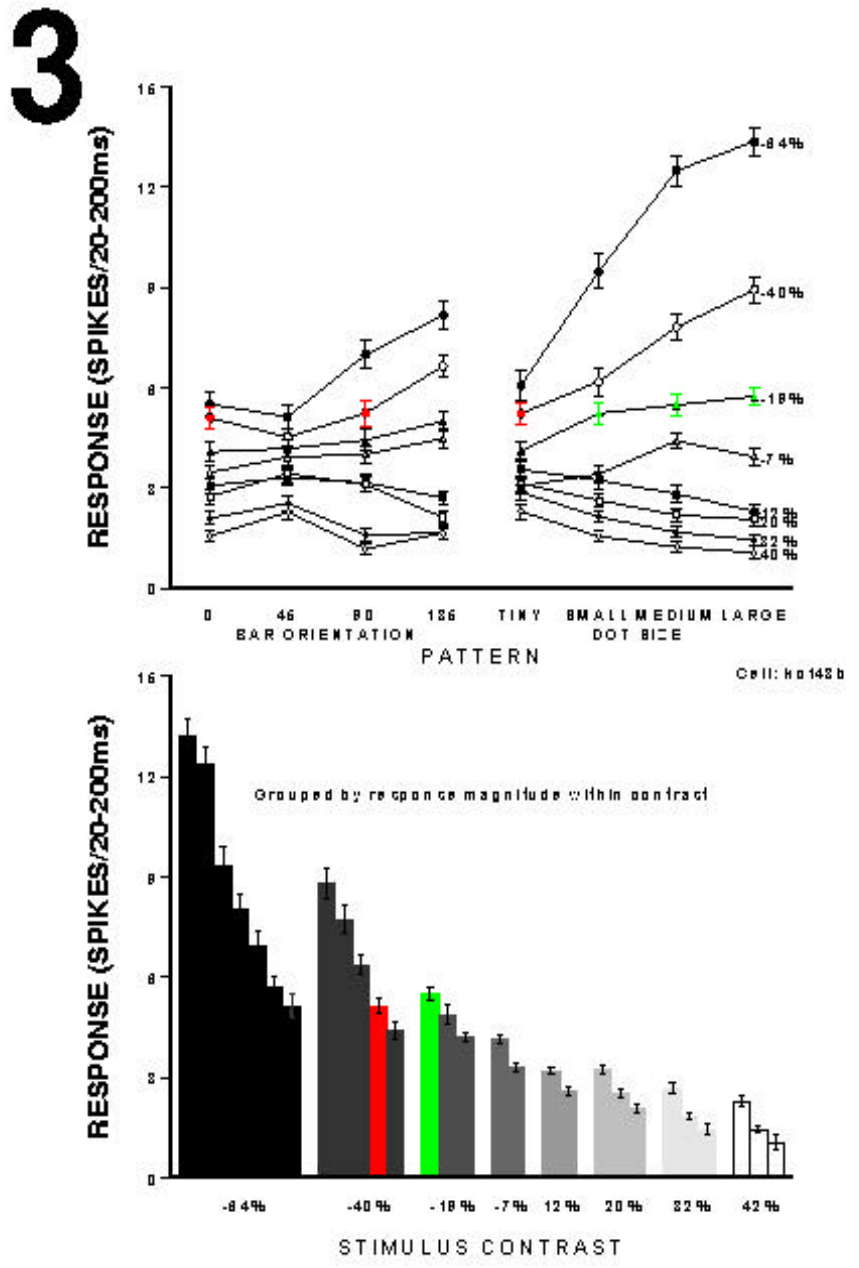


**Figure 3. Response of a single neuron to the different stimulus configurations (pattern) and contrast levels**. The method used to equate response magnitudes to stimuli at different contrast levels is shown. **Upper:** mean response magnitude (± SEM) of one cell (kof48b) to the eight different stimulus configurations (pattern) is shown. Each line represents the responses to one contrast. The left shows the responses to bars at four orientations, the right shows the responses to the dot stimulus at 4 sizes. Significant effects of contrast ($F_{[7,3416]}$ = 528.1, $p < 0.0005$) and stimulus configuration ($F_{[7,3416]}$ = 26.3, $p < 0.0005$) were observed as was the interaction between contrast and stimulus configuration ($F_{[49,3416]}$ = 20.6, $p < 0.0005$). **Lower:** For each contrast, the mean of responses grouped from the upper section according to response magnitude rather than stimulus pattern. For example, the stimuli in the upper figure marked in red were averaged and formed the group depicted by the red bar. Likewise, the stimuli in the upper figure marked in green were averaged and formed a second magnitude group (green bar). The groupings allowed equating by response magnitude for different contrasts to examine trends within the data. The equivalent response magnitude groups were used in the subsequent latency analysis.

# RESULTS

- As expected changes in stimulus contrast produced changes in response magnitude. Changes in stimulus configuration also produced pronounced changes in response magnitude (Figure 3, upper). Selection of stimulus groups allowed equating response strength across different stimulus contrasts (Figure 3, lower).

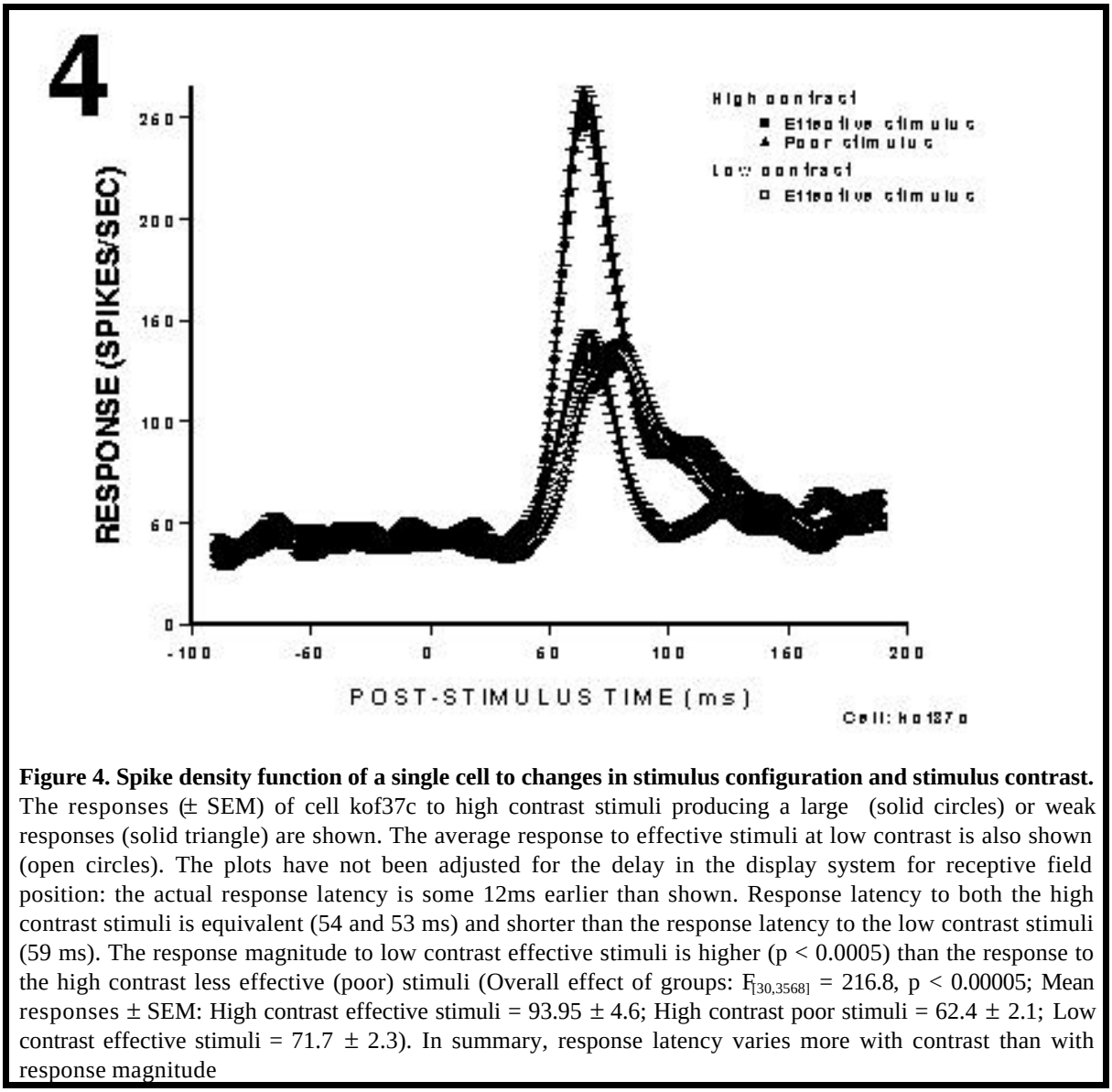


**Figure 4. Spike density function of a single cell to changes in stimulus configuration and stimulus contrast.** The responses (± SEM) of cell kof37c to high contrast stimuli producing a large (solid circles) or weak responses (solid triangle) are shown. The average response to effective stimuli at low contrast is also shown (open circles). The plots have not been adjusted for the delay in the display system for receptive field position: the actual response latency is some 12ms earlier than shown. Response latency to both the high contrast stimuli is equivalent (54 and 53 ms) and shorter than the response latency to the low contrast stimuli (59 ms). The response magnitude to low contrast effective stimuli is higher ($p < 0.0005$) than the response to the high contrast less effective (poor) stimuli (Overall effect of groups: $F_{[30,3568]} = 216.8$, $p < 0.00005$; Mean responses ± SEM: High contrast effective stimuli = 93.95 ± 4.6; High contrast poor stimuli = 62.4 ± 2.1; Low contrast effective stimuli = 71.7 ± 2.3). In summary, response latency varies more with contrast than with response magnitude

- For many cells (29/41, 71%) the response latency to low contrast stimuli was longer than that seen to response magnitude matched stimuli of high contrast (e.g. Figure 4).
- Response latency was more strongly influenced by stimulus contrast than by response magnitude (Figure 5). At high contrasts, changes in stimulus effectiveness produced little change in response latency despite large changes in response magnitude (left 2 bars, Figure 5 upper and lower). A decrease in stimulus contrast can produce a large increase in response latency with little change in response magnitude (right 2 bars, Figure 5 upper and lower).

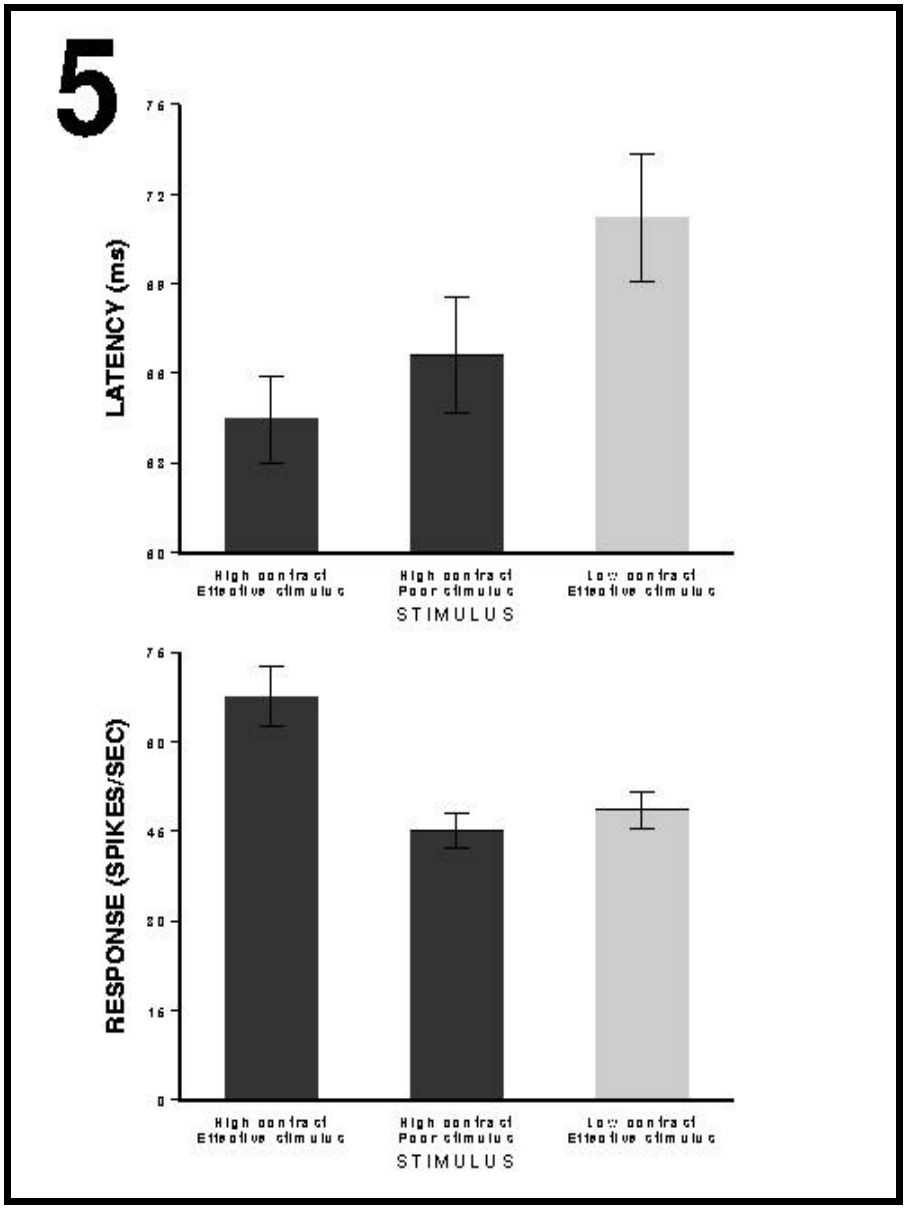


**Figure 5. Analysis of the relationship between response magnitude and latency at the population level**. **Upper:** Response latency increases more with change of stimulus contrast than with change of effectiveness of stimulus. 2-way ANOVA (response latency and cell) indicated that different cells had significantly different latencies ($F_{[40,80]} = 7.2$, $p < 0.00005$) and that there was an overall effect of stimulus condition ($F_{[2,80]} = 10.5$, $p = 0.0001$). *Post-hoc* testing suggests that both high contrast stimulus groups have the same latency ($p > 0.2$) and both were significantly shorted than the response latency to low contrast stimuli ($p < 0.01$ each comparison). **Lower:** The changes in response latency to change in stimulus contrast (upper section) is not due to changes in response magnitude. 2-way ANOVA (response magnitude and cell) indicated a significant effect of cell ($F_{[40,80]} = 17.0$, $p < 0.00005$) and of stimulus condition ($F_{[2,80]} = 67.9$, $p < 0.00005$) on response magnitude. A large change in response magnitude occurred at high contrast with the change in stimulus effectiveness (71.1 and 48.5 spikes/sec, $p < 0.00005$). There was no significant change of response latency between these two stimulus classes (upper section). Responses to the selected low contrast stimuli were on average statistically indistinguishable from responses to the selected less effective stimuli at high contrast ($p > 0.05$), yet there was a significant change in measured response latency (upper section).

# CONCLUSIONS

- As seen in two cortical regions, the response magnitude and latency of LGN neurons are not inexorably linked. The response-latency properties of the cortical neurons can be explained in part by response properties of LGN neurons.
- The effect of contrast on response latency can not be explained only in terms of response magnitude since contrast induced changes in latency occur without changes in response magnitude.
- As with striate cortical neurons, response latency of LGN neurons shows greater dependency on stimulus contrast than response magnitude.
- Like striate cortical neurons, changes in stimulus configuration produce large changes in response magnitude with little effect on response latency.

## References

Oram, M.W. and Perrett D.I. (1992). Time course of neural responses discriminating different views of the face and head. *Journal of Neurophysiology, 68, 70-84.*

Gawne, T.J., Kjaer, T.W. & Richmond, B.J. (1996). Latency – another potential code for feature binding in striate cortex. *Journal of Neurophysiology, 76, 1356-1360*