Dynamics of contrast-gain controls in pattern vision

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1. INTRODUCTION

We examined contrast gain-controlling processes using the probed-sinewave paradigm with element-arrangement patterns. In our experiments, a background pattern is shown for a second, then a probe is flashed briefly, and then the background is shown again for a second. The patterns are grids of (vertical or horizontal) Gabor-patch elements. At right (Fig 1) is a piece of our background pattern composed of vertical Gabor elements (all at the same contrast).

We present the background pattern in two different ways:

- Flickering background: The contrast of the Gabor elements flickers sinusoidally over time.
- Steady background: The contrast of the Gabor elements is steady over time.

Fig 1. Vertical Gabor-element pattern.
The actual pattern was 15x15, this is just a 5x5 piece.
The Gabor-element intensity profile is shown at left.
We also used a horizontal Gabor-element pattern.

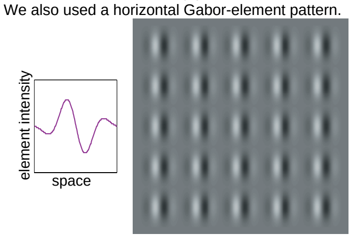
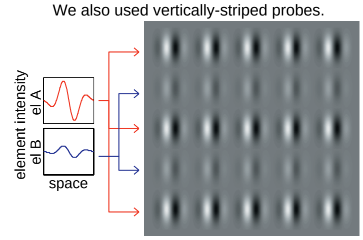


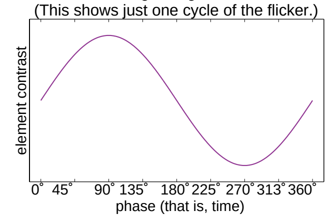
Fig 2. Horizontally-striped probe.
The contrast of "el A" has increased.
The contrast of "el B" has decreased.
We also used vertically-striped probes.



A probe is presented on one of these backgrounds. If we call the elements in every-other-row (or every-other-column) of a pattern "el A", and the elements in the other rows (or other columns) "el B", then the probe consists of a change in the contrast of "el A" and a change in the contrast of "el B", producing stripes in the overall pattern. At right (Fig 2) is a horizontally-striped probe. The subject's task is to identify the orientation of the stripes (vertical or horizontal).

We were looking to drive the normalization network (shown later in Fig 10) by the sinusoidal flickering of the background. We may indeed be doing so. However, there is a much larger effect that we have been drawn to. This effect can be accounted for by a rectifying contrast gain control process which we call the Buffy process.

Fig 3. Element contrast over time
in the flickering background condition.
(This shows just one cycle of the flicker.)



2.1. STIMULUS WITH FLICKERING BACKGROUND

With a flickering background the contrast of the Gabor elements flickers sinusoidally over time as outlined at right (Fig 3). Below (Fig 4a-h) is a pattern at 8 moments in time. At top-left of each panel, the contrasts of "el A" and "el B" over one cycle are sketched. (The contrasts of "el A" and "el B" are the same at any moment in time since this is just the background without a probe). The yellow bar indicates the particular moment in time. At top-right of each panel, the intensities of "el A" and "el B" over space are sketched.

2.2. FLICKERING WITH PROBE

On each trial we show a probe at one of eight phases: 0˚, 45˚, …, or 315˚. Below are two examples. Fig 5a shows a vertically-striped probe presented at phase=180˚ (negative zero-crossing). Fig 5b shows a probe presented at phase=90˚ (peak). This probe is produced by increasing the contrast of "el A" and decreasing the contrast of "el B". (A few details: The probe is shown for 35 or 80 msec. Within a session, there are 8 interleaved staircases, 1 for each phase, that determine probe-threshold by increasing and decreasing the contrast changes of "el A" and "el B". Within a session, all trials have the same background flicker frequency: 0.5, 0.67, 1, 1.33, 2, 2.67, 4, or 8 Hz.)

2.3. STIMULUS WITH STEADY BACKGROUND

With a steady background the contrast of the Gabor elements is steady during a trial (except when the probe is presented). We have two different steady background conditions:

- regular-steady background (approximates very slow flicker): There are 8 sub-conditions; these correspond to the 8 phases (shown in Fig 4a-h). The steady contrast level of the elements is the same, for a given phase, as the contrast level in the flickering condition at that same phase. For example, when measuring probe-threshold at phase=0˚, the steady background is the same as the *image* in Fig 4a. At phase=45˚, the same as the *image* in Fig 4b. Etc.
- Buffy-steady background (approximates very fast flicker): The steady contrast level of the elements is always the same as the contrast level at the zero-crossings in the flickering stimulus. So, the steady background, at all phases at all times, is the same as the *image* in Fig 4a (phase=0˚).

2.4. STEADY WITH PROBE

- Probe on a regular-steady background: A probe is produced by increasing the contrast of "el A" and decreasing the contrast of "el B" relative to the steady contrast level. So, for example, a probe at 180˚ is the same as the *image* in Fig 5a, and a probe at 90˚ is the same as the *image* in Fig 5b.
- Probe on a Buffy-steady background: To produce a probe, the contrasts of "el A" and "el B" change to the same levels used in the regular-steady case. So, again, a probe at 180˚ (90˚) is the same as the *image* in Fig 5a (Fig 5b). But the steady contrast level (preceding and following the probe) differs for the Buffy-steady and regular-steady conditions as shown in Fig 6 (for a probe at 90˚).

The differences between the steady conditions are shown for all phases in Fig 7. Each panel shows the a steady background (in purple) and a probe ("el A" in red, "el B" in blue). See, for example, that a Buffy-steady 270˚ probe is made by decreasing the contrasts of "el A" AND "el B" relative to the steady background!

Fig 4. Flickering background (without probe) at ...

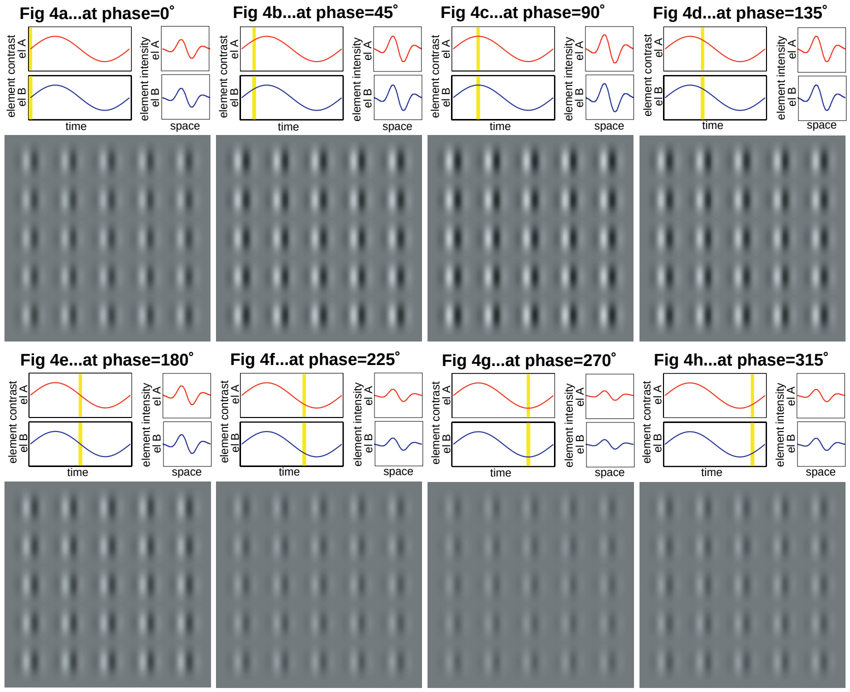


Fig 5. Flickering background WITH PROBE at ...

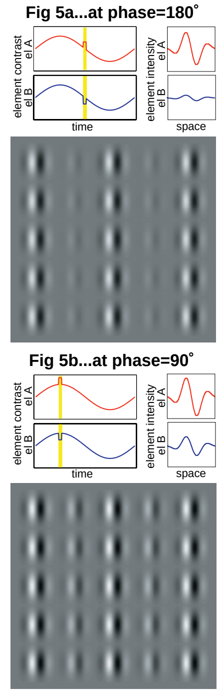


Fig 6. Steady backgrounds with probe at phase=90˚.
{The probe is the same for the Buffy-steady and regular-steady. The steady contrast level (preceding & following the probe) is different.}

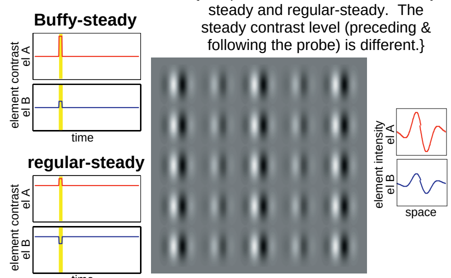
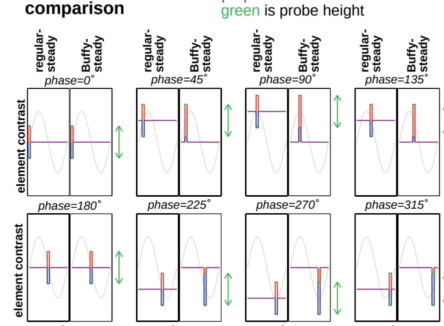


Fig 7. Steady conditions comparison

red is "el A" contrast
blue is "el B" contrast
purple is "el A" & "el B" contrast
green is probe height



3.1. RESULTS for subject J

At right are results for subject J.

- Fig 8a shows probe-threshold versus phase curves. Each panel shows one frequency of the flickering background (labeled at the top of the panel). In each panel, the cycle of probe-thresholds is repeated twice for clarity.
- Fig 8b shows the same curves as Fig 8a, but the curves are all superimposed on one panel. The same colors are used in the two plots.

3.2. RESULTS summary for J

At right are two summary measures for subject J. These are calculated from the probe-threshold versus phase curves (shown in Fig 8a).

- Fig 8c shows dc-level, the average probe-threshold level across phase, plotted against frequency.
- Fig 8d shows peak-to-trough the maximum probe-threshold minus the minimum probe-threshold across phase, plotted against frequency.
- The smooth curves are simple fits.

3.3. RESULTS summary for all

At right are the two summary measures for all the subjects. Each subject is plotted with a different color.

- Fig 8e shows dc-level for each subject: dc-level generally decreases as frequency increases.
- Fig 8f shows peak-to-trough for each subject: peak-to-trough generally increases as frequency increases.
- The smooth curves are simple fits.

3.4. RESULTS light adaptation

The probed-sinewave paradigm has been used to study light adaptation. Such an experiment uses a large, homogeneous background and a small, homogenous probe. At right are results from many such experiments.

- Fig 9a shows dc-level increasing and then decreasing as frequency increases.
- Fig 9b shows peak-to-trough decreasing as frequency increases.

3.5. RESULTS

We were very confused by our results at first. We had expected that peak-to-trough would decrease when the frequency was high enough. We had expected that dc-level would stay much the same (or increase) with frequency as is the case in light adaptation (until some turnaround frequency as shown in Fig 9a). That is, the 0 Hz (regular-steady) condition should be quite easy (have low probe-thresholds on average), but it is actually the hardest (see Fig 8e). Why is this?

Fig 8a. probe-threshold vs phase curves for subject J

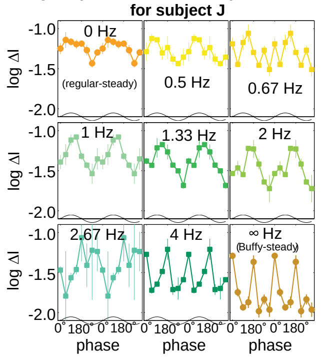


Fig 8b. probe-threshold vs phase curves for subject J

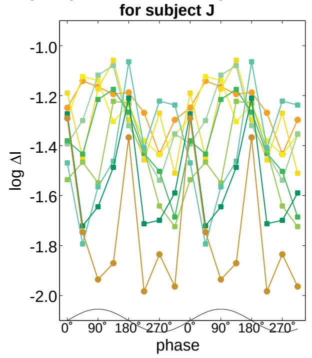


Fig 8c. dc-level for subject J

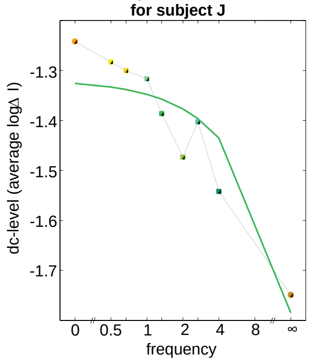


Fig 8c. peak-to-trough for subject J

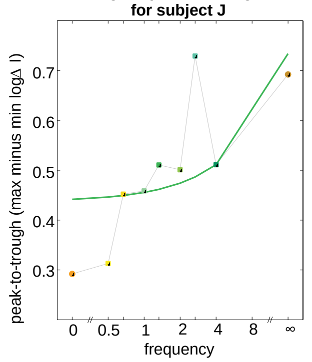


Fig 8e. dc-level for all subjects

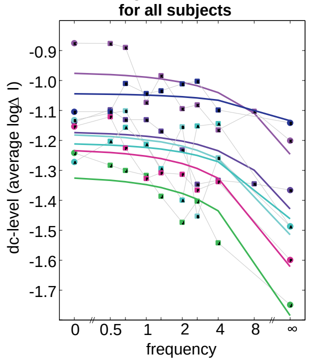


Fig 8f. peak-to-trough for all subjects

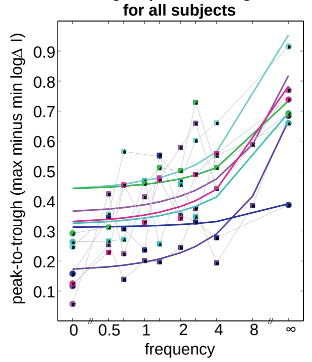


Fig 9a. dc-level from light adaptation studies
from Wolfson & Graham (submitted): *Forty-four years of studying light adaptation using the probed-sinewave paradigm*

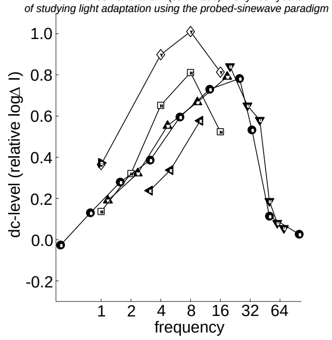


Fig 9b. peak-to-trough from light adaptation studies
from Wolfson & Graham (submitted): *Forty-four years of studying light adaptation using the probed-sinewave paradigm*

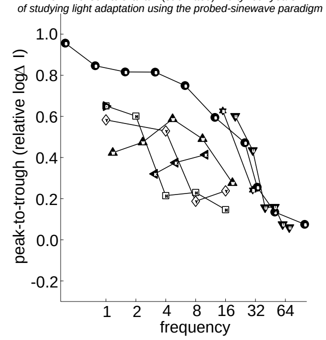
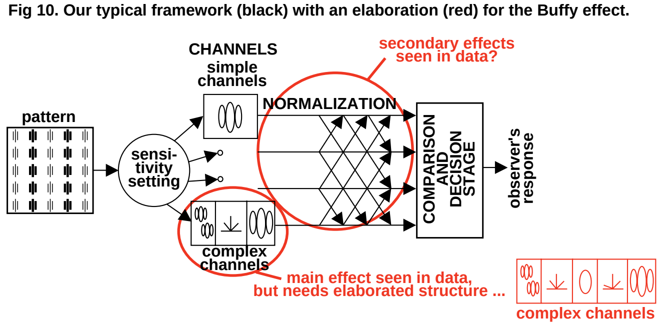


Fig 10. Our typical framework (black) with an elaboration (red) for the Buffy effect.



4. BUFFY PROCESS

Suppose there is some process (the Buffy process) that adapts to the contrast level over, say, 200 msec. In the 0.5 Hz condition, results should look rather like in the 0 Hz (regular-steady) condition since the process would adapt to about the same level in both conditions. But around 4 Hz, this Buffy process will adapt to the average contrast level over a whole cycle of flicker (that is, the contrast level at the zero-crossings). The ∞ Hz (Buffy-steady) condition tests this by actually adapting subjects to that contrast level. If our logic is correct, as frequency increases, the results should look more and more like the Buffy-steady results, which is what we see (Fig 8a).

The Buffy-steady condition (∞ Hz) shows greatest sensitivity at both the peak (90˚) and trough (270˚). This tells us that the Buffy-process' output is higher the greater the change in contrast. This can be an increase or decrease in contrast (from the currently adapted-to contrast level). That is, the process does not care about the direction of change, just that there is a change. Where might this process live?

The Buffy-steady result *cannot* be accounted for in our typical framework (Fig 10, black lines), but it *can* be accounted for by the following elaborated complex channels (sketched on Fig 10 in red):

1st stage receptive fields tuned to the elements
➔ pointwise nonlinearity
➔ 2nd stage excitatory-only receptive fields (big enough to integrate over individual elements; outputs will approximately measure local element contrast)
➔ pointwise nonlinearity (unbalanced, full-wave rectification of both on and off types)
➔ 3rd stage receptive fields tuned to the striped arrangement

The Buffy process is inherently about contrast, not intensity. Thus, the process cannot be modeled by any simple change to the outputs of the 1st stage receptive fields – that is, subtractive or multiplicative adaptation – nor to the nonlinearity between the 1st and 2nd stages.

The Buffy process can be modeled by assuming contrast adaptation affects the pointwise rectification nonlinearity between the 2nd and 3rd stage receptive fields. In particular, this nonlinearity is assumed to depend on its recent input history, so its output is zero for an input equal to the recent time-averaged input (the "current adaptation level"), and its output is positive (but asymmetrically so) for inputs that are smaller or larger than the current adaptation level.

5. CONCLUSION

We find evidence for a rectifying contrast-gain controlling process (the Buffy process). This process integrates for less than 200 msec. It fits nicely into "elaborated" complex channels (see red sketch in Fig 10).

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