

Amodal completion affects lightness perception

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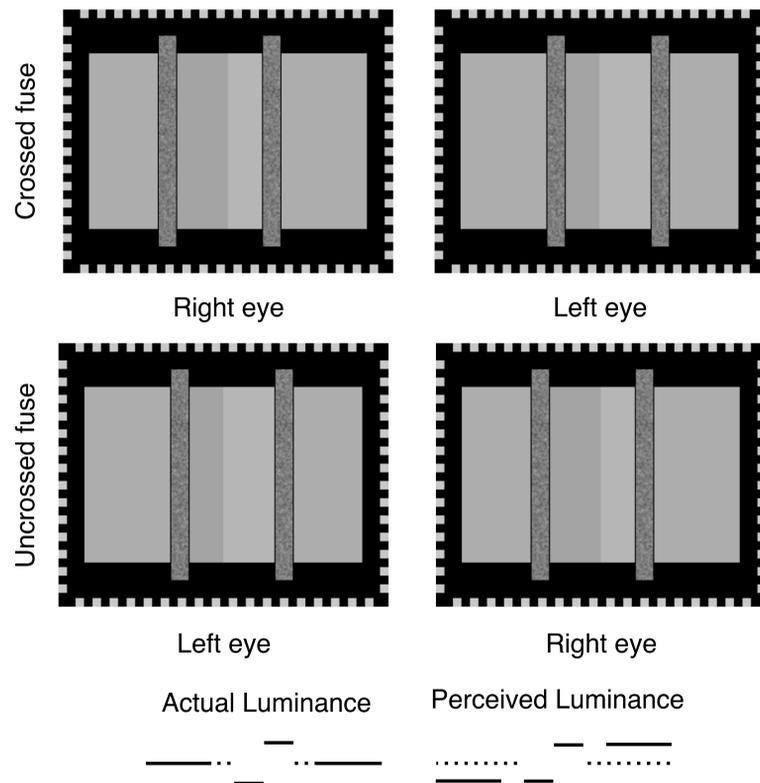
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Introduction

Amodal completion - when two spatially separated surfaces appear to be grouped together behind an occluder - is one of the mechanisms which can facilitate perceptual grouping and may influence surface lightness.

In the stimulus shown below the right and left flanking regions are identical, but they appear to have different luminances, because the surface is amodally completed behind the occluder bars and lightness information from the central region affects the perceived luminance of the flanks. We refer to this illusory percept as the *Lightness Effect*.

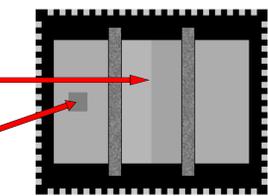


Behavioral measurement of the lightness effect

3 observers participated in a behavioral experiment (3D presentation in a stereoscope)

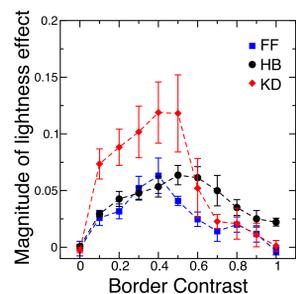
11 border contrast levels tested, 5 trials for each level, unlimited time

Task: Adjust the matching patch until it appears to have the same luminance as the opposite flank.



$$\text{Contrast} = L_{\max} \cdot L_{\min} / L_{\text{mean}}$$

Results

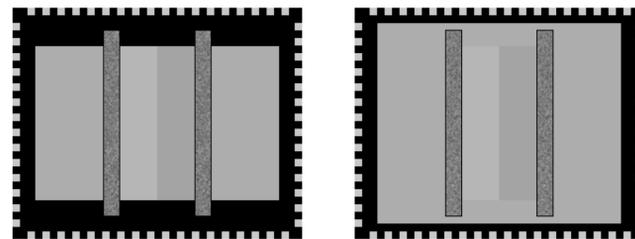


Magnitude of the lightness effect is defined as the contrast between the matching patch and its background

For all three observers, the lightness effect first increased as the contrast of the central border increased, but then started to decrease around 0.5 border contrast level and largely diminished at the contrast level of 1

FMRI Experiment

Stimuli



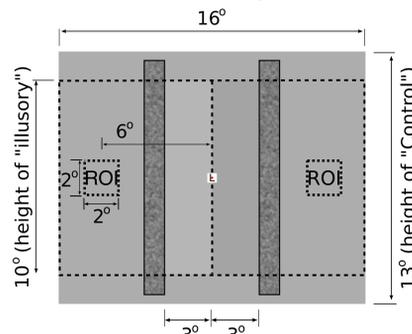
2D presentation

The "Illusory" and "Control" stimuli have the same luminance pattern along a horizontal cross-section, but only the "Illusory" stimulus produces a strong lightness effect

Contrast of the border: 0.25 for both the "Illusory" and "Control" stimuli

3 Observers; 1 Anatomical (3D) scan
1 ROI scan; 4 Experimental scans
Siemens Trio 3T scanner; TR = 2sec.

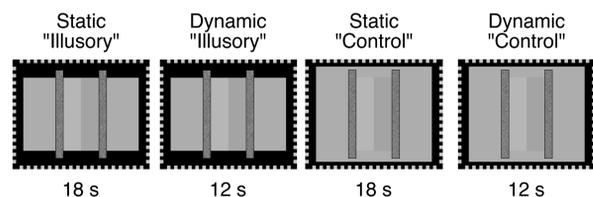
ROI definition and experimental design



Cortical activity was measured in regions corresponding to the flanks of the dynamically presented versions of the stimuli.

During the dynamic presentation only the central portion reversed its contrast polarity (square-wave modulated counter-phase flicker). Even though the flanks remained constant in luminance their apparent lightness varied in the "Illusory" condition. This lightness effect was absent or much weaker in the "Control" condition

Fixation task: Throughout the entire scan observers performed a demanding fixation task that required them to detect a target letter among distractors during rapidly changing presentation of these letters.

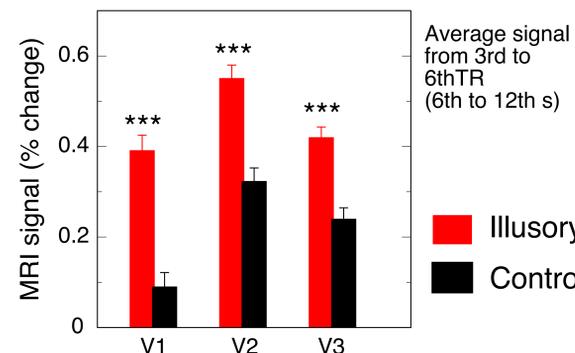
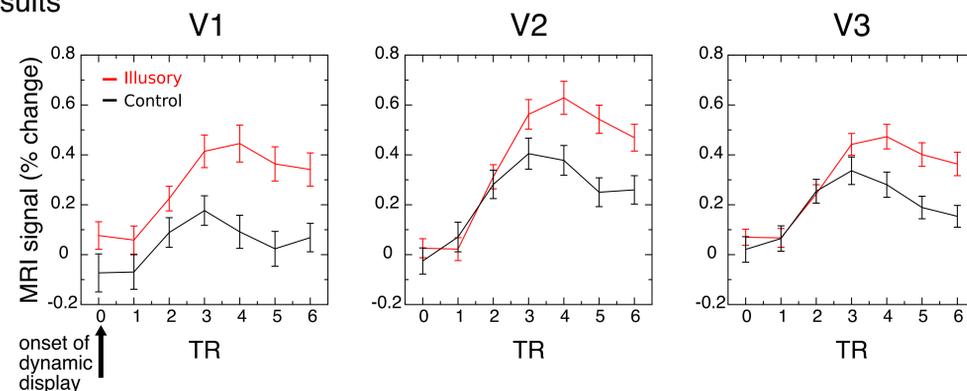


Possible Outcomes:

H₀: No signal difference because luminance profiles are identical
H₁: "Illusory" > "Control" because of the illusory luminance variation

Analysis: Signal within ROIs was extracted and first normalized by a common baseline computed as the average of the last two time points of all static presentation blocks in a scan, and then event-related averaged.

Results



We found significantly larger cortical response to the "Illusory" condition in V1, V2 and V3 (***) $p < 0.001$, error bars one s.e.m.

This suggests that the cortical activity correlates with lightness variations, not localized luminance variations alone.

The difference between the "Illusory" and "Control" conditions also suggests that the activity cannot be a direct response to the distant luminance variations.

These results are consistent with our previous study (Boyaci, Fang, Murray and Kersten 2007)

Modeling the lightness effect

What causes the lightness effect? Perceptual grouping of the three separated surfaces into a single plane behind the occluder apparently plays an important role. Another important factor seems to be assignment of similar lightnesses to nearby regions on a surface. We have put these possible rules together and tested them computationally (see Kersten, Madarasm, 1995).

Let $L_k(r) = a_k r + b_k$, $k=1,2,\dots$ be the perceived luminance levels and let $g_k(r)$ be the probability that input data $O(r)$ at r is generated by the k -th level (L_k)
Let the effective energy function be:

$$E = \lambda_I \sum_{k,r} g_k(r) \underbrace{(L_k(r) - O(r))^2}_{I_k(r)} + \lambda_D \sum_{k,r,l} g_k(r) g_l(r+1) \underbrace{((L_k(r) - L_l(r+1) - O(r))^4)}_{D_k(r)} \begin{matrix} \text{if } O(r) > T_D, \\ \text{otherwise ignored} \end{matrix} + \lambda_H \sum_{k,r} g_k(r) \exp(\beta_H |L'_k(r)|) + \lambda_G \sum_{k,r} g_k(r) (1 - g_k(s)) \begin{matrix} N_r = [r - \eta_r^-, r + \eta_r^+] \\ \text{such that } |O(r) - O(s)| / |r - s| > T_G, \text{ then } N = (r - \eta_r^-, r + \eta_r^+) \\ \text{where } \eta_r^- \text{ and } \eta_r^+ \text{ denote the location of discontinuity} \end{matrix} + T \sum_{k,r} g_k(r) \log g_k(r)$$

Intensity matching

Discontinuity preserving

Homogeneity

Grouping

Entropy

It is possible to minimize this energy function by solving for $dE=0$ with respect to both $g_k(r)$ and L_k . Minimization with respect to $g_k(r)$ using Lagrange multiplier method (see Weiss & Adelson, 1994) leads to

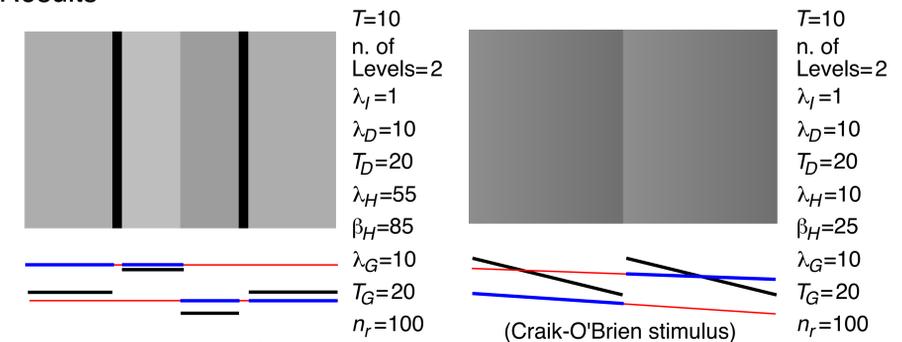
$$g_k(r) = \frac{\exp(-1/T (\lambda_I I_k^2(r) + \lambda_D \sum_l g_l(r+1) D_k(r) + \lambda_H \exp(\beta_H |L'_k(r)|) + \lambda_G \sum_{s \in N_r} 1 - g_k(s)))}{\sum_l \exp(-1/T (\lambda_I I_l^2(r) + \lambda_D \sum_l g_l(r+1) D_l(r) + \lambda_H \exp(\beta_H |L'_l(r)|) + \lambda_G \sum_{s \in N_r} 1 - g_l(s)))}$$

and the minimization with respect to L_k amounts to

$$L_k^* = \text{argmin}_{L_k} \left\{ \sum_r (\lambda_I g_k(r) I_k^2(r) + \lambda_D \sum_l g_l(r+1) D_k^4(r) + \lambda_H g_k(r) \exp(\beta_H |L'_k(r)|)) \right\}$$

We repeat these two steps iteratively. By solving the second equation we find the form of the perceived luminance levels that fit the data best, and by solving the first equation we find the level that most likely generated the data at a location (r). Note that these are the same two steps as the ones in the well known EM algorithm

Results



— Luminance profile
— Levels, L_k , that minimize the effective energy
— The most likely perceived luminance level at the given position:
 $L(r) = L_{k^*}(r)$ where $k^* = \text{argmax}_k g_k(r)$

References

Boyaci, H., Fang, F., Murray, S.O., Kersten, D. "Responses to lightness variations in early human visual cortex," Current Biology, in press (2007).
Kersten, D., Madarasm, S. "The visual perception of surfaces, their properties, and relationships," DIMACS Series in Discrete Mathematics and Theoretical Computer Science, 19 373-389 (1995).
Weiss, Y., Adelson, E.H. "Perceptually organized EM: A framework for motion segmentation that combines information about form and motion," M.I.T. Media Laboratory Perceptual Computing Section Technical Report No. 315.