A Neurocomputational Theory of Spontaneous Attentional Selection

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Where we look with our next fixation or our selection of which movie to see or book to read is decidedly non random. What controls this selection when an individual is not hungry, avoiding harm, engaged in deliberate search, etc.? And how can the selection be manifested in real time, at the rate of three visual fixations per second? The surprising discovery of a gradient of mu-opiate receptors (ligand termed "endomorphin") in the macaque ventral cortical visual pathway, a system presumed to subserve visual recognition, may provide the key for understanding the spontaneous selectivity of perception and thought. These receptors are sparse in the earliest stages, e.g., V1 and V2, but dense in the later stages (inferior temporal and parahippocampal cortices), where perceptual information activates the products of past experience. A simple mechanism may account for a vast range of spontaneous perceptual selectivity: Experiences are preferred that maximize the rate of endomorphin release. Such inputs will tend to be those that are richly interpretable (not just complex) insofar as they would produce high activation of associative connections in areas that have the greatest density of mu-opiate receptors. Once an input is experienced, however, competitive learning would serve to reduce activity, resulting in less endomorphin release, leading to habituation and boredom. Neuroimaging (fMRI) data provide general confirmation of this account including the unexpected finding that scene preference is inversely related to attentional demands.

Keywords: Spontaneous attentional selection, perceptual and cognitive pleasure, scene judgments, fMRI when viewing scenes, cortical opiate receptors.

Introduction

It has long been noted that eye fixations during the viewing of a novel scene are hardly random but are made to "regions of interest." We tend not to look at blank walls or random masses. This perceptual selectivity based on interest is apparent whenever we are not meeting basic biological needs (e.g., for food, survival, etc.) or searching for a target and is not confined to vision but is apparent in whom we talk to and what we talk about, the books we read, etc. The great unknown in this account of selective attention was what it is that defines "interest." We have started to use event-related functional magnetic resonance imaging to investigate the brain activity associated with the viewing of visual scenes differing widely in their initial preferences. By studying the BOLD response to the initial encounter with a scene and its variation as a function of repetition of these scenes, we hope to gain insight into the brain mechanisms underlying visual "interest."

This research is motivated by a neurocomputational theory of perceptual and cognitive affect (Vessel & Biederman, 2001). The theory posits a specific function for the surprising discovery of Lewis et al. (1981) of a gradient of mu-opiate receptors (ligand termed “endomorphin”) in the ventral cortical pathway of the macaque. These receptors (and by implication, opiate activity) are sparsest in V1 and monotonically increase in density to V2, V4, IT and the parahippocampal gyrus (Fig. 1). A similar gradient was found between primary and secondary auditory cortex. Why would opiate activity be associated with a perceptual pathway? Our proposal is that novel but interpretable perceptual inputs would lead initially to the most neural activity--and hence opiate activity--in the anterior stages of the ventral pathway (IT and the parahippocampal gyrus). High activity would then be associated with high pleasure (or interest). However, with repetition of a pattern, competitive interactions would result in less activity (Miller et al., 1993; Sobotka & Ringo, 1994). The magnitude of the opiate activity would subserve perceptual and cognitive preference, resulting in a preference for patterns which are both novel (because they have yet to undergo competitive interactions) and richly interpretable (because such patterns would initially activate a rich set of associations in areas that can manifest dense opiate activity). A random, uninterpretable mass of elements would elicit very little late, interpretative activity whereas a blank screen would not only produce little or no late activity, it would produce only minimal early activity.

The neurocomputational theory sketched above has the potential of accounting for how interest can be expressed in real time in a perceptual pathway and why habituation occurs so that, in general, as stimuli become fully understood either because of their initial simplicity or through repeated encounters, there is a decline in the pleasure of encountering them again.

Overview of the Research Program

We are investigating changes in visual preference over repeated exposure with the goal of developing robust imaging and pharmacological methods to directly test the neurocomputational theory described above. The major research questions we aim to address are 1) whether there are different brain loci mediating preference and repetition, 2) how visual preference changes with repeated exposure, and 3) why are some scenes preferred to others.

Behavioral Studies of Scene Preference and Repetition

Subjects rated the scenes on a one (don't like it) to seven (really like it) scale. The images depicted a wide variety of scenes, ranging from close ups of man-made objects to scenic vistas of natural landscapes. The averages of the subjects' ratings on this pretest were then used to sort the images by preference levels and inter-subject variability. Fig. 2 shows an example of the highest and lowest rated scenes.

There was a steady decline in rated preference with repetition (Fig. 3) although there is high stability based on the initial preference. The repetitions were widely separated and the design avoided a confound of repetition with time in the session. This was true of the fMRI stud as well.

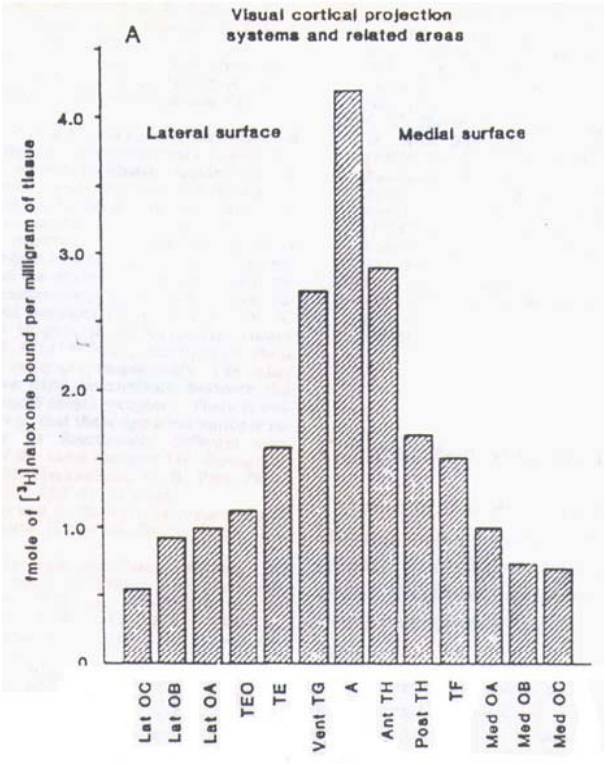

Figure 1. The density of μ -like opiate receptors as labeled by tritiated naloxone is relatively low in early cortical visual areas (OC = striate cortex, OB = peristriate, OA = preoccipital; TH = Parahippocampal Gyrus; A = Periamygdalar Gyrus which is part of the parahippocampal gyrus in humans) and gradually increases on both the lateral and medial surfaces of the ventral visual pathway (from Lewis et al., 1981).

Factors Influencing Scene Preference

Why do people prefer one scene to another, or one part of a scene over another part? Kaplan (1992) proposed that a considerable proportion of the variance in scene preferences might reflect an evolutionary mechanism that induces people to select places for habitation that a) provide a vista for "reconnaissance," so that potential threats, food sources, etc., can be detected at a distance, and b) provide "refuge," so that the people themselves, when scanning the vista, can not themselves be detected. Other factors might be those that provide navigable landmarks or indicate likely sources of sudden change.

We assessed the ability of such factors to predict initial preferences for scenes and the rate at which those preferences decline over repeated presentations.

A group of twelve subjects rated all 200 images on how well they agreed with the following characteristics:

- **Coherence**: How rapidly and easily did you understand what the scene was about?
- **Legibility**: How easily would you be able to determine where you were in the scene and navigate through it?
- **Mystery**: How likely is it that you would obtain different information from changes in your vantage

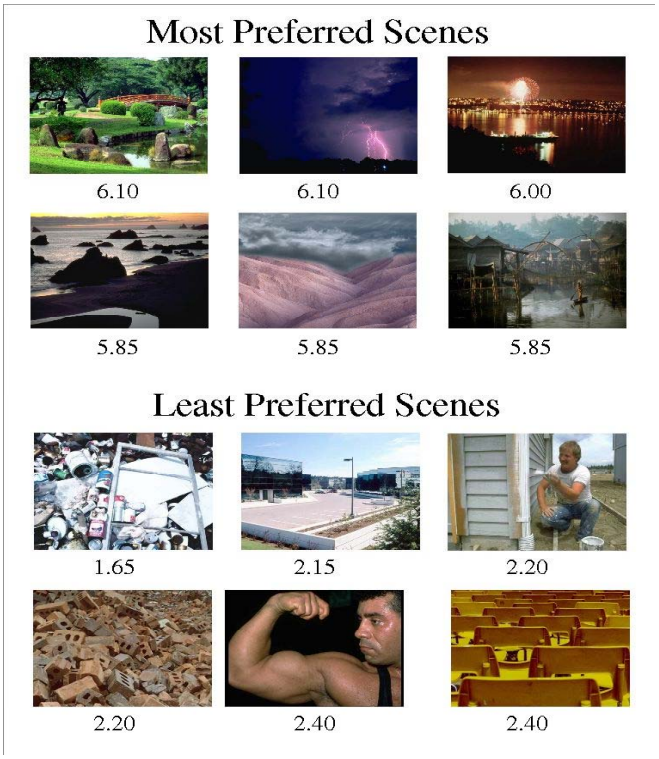

Figure 2. The top six images had the highest average preference ratings across subjects, while the bottom six were, on average, the least preferred.

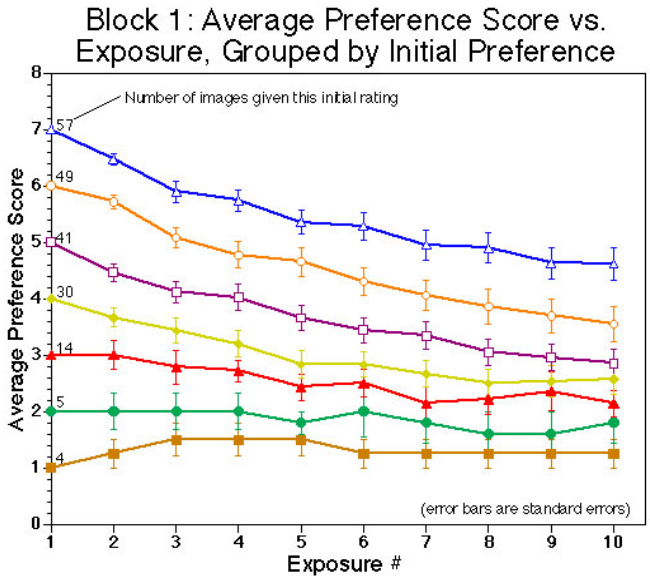

Figure 3. Preference habituates with repeated exposure.

point, or that something new might appear?

- **Vista**: How good is the view? Can you see a wide expanse of area, or for a long distance?
- **Refuge**: Is there a position in the scene where you can have a good vantagepoint without being seen?

These five factors, plus ratings by four other subjects on a natural vs. urban dimension, were correlated with the initial preference ratings and habituation rates in the earlier experiments. A multiple linear regression analysis of the results indicates that these factors together can account for 63% of the variance in subjects' initial preference scores.

Neuroimaging

Subjects viewed each of 60 scenes, each repeated five times with a number of "buffers" over a two-hour session in the magnet. An event related, jittered design (Buckner & Braver, 1999) was used so that the response to individual scenes could be estimated. The fMRI results were generally consistent with the theory. The parahippocampal gyrus, though only on the left side, showed greater activity for highly preferred scenes than scenes of low preference. This was not simply a feedforward effect in that more posterior areas, such as LO, showed the opposite pattern. BOLD activity declined over five repetitions in the parahippocampal gyrus but showed an initial decline and then a strong recovery in areas associated with attentional effort. The activity appears to represent more active processing of the scene as subjects become habituated (bored) with the repetitions. They reported searching for details in the scenes and disliking the scenes after they were repeated. Interestingly, only the disliking—not the active processing--was reflected in parahippocampal activity.

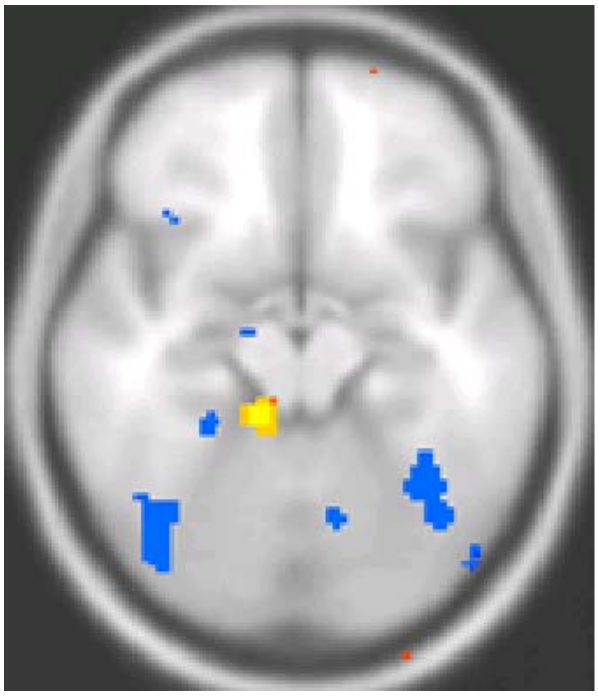

Fig. 4. Parahippocampal gyrus showed greater activity for scenes of high than low preference. More posterior areas show the opposite pattern.

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