

# I Think Therefore I Feel: Possible Neural Mechanisms for Knowledge-based Pleasure

Daniel S. Levine

**Abstract**—How do we feel pleasure from acquiring new information? How is that pleasure related to our curiosity about that information? We outline a neural theory of how information-based pleasure arises from a network involving association cortex, dorsolateral prefrontal cortex, orbitofrontal cortex, striatum, opioids, and dopamine.

## 1. THE KNOWLEDGE INSTINCT AND ITS ATTENDANT EMOTIONS

The drive by humans and other animals to understand their environments as deeply as possible has long been recognized by psychologists [1]. Perlovsky [2, 3] has described this drive as a *knowledge instinct*, a biological curiosity drive that can be comparably powerful to other biological drives such as those for food, sex, and safety.

Perlovsky notes that emotions are linked to satisfaction or dissatisfaction of basic drives, based on a theory developed in [4]. In the case of the knowledge instinct, there is behavioral evidence for pleasure from satisfied curiosity [5] and displeasure from cognitive dissonance [6, 7]. Since the curiosity drive typically engages a higher level of processing than the hunger or sex drives, its attendant emotions are thought to be qualitatively different from the emotions attendant to those other drives, and related to the sense of the beautiful [8].

The notion of a knowledge instinct is not universally accepted in the scientific community. Neuroscientists and psychologists, and even more the general public, still often treat cognition and emotion as separate processes and resist the notion that one is attendant on the other.

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D. S. Levine is with the Department of Psychology, University of Texas at Arlington, Arlington, TX 76019-0528, USA (phone: 817-272-3598; fax: 817-272-2364; e-mail: [levine@uta.edu](mailto:levine@uta.edu)). The work was done under a consulting arrangement with Solid State Scientific Corporation, Nashua, NH, USA 06030. The author also acknowledges Evgenia Malaia and Leonid Perlovsky for comments on an earlier version.

The resistance to combining emotional and cognitive processes persists despite the telling blows to mind-body dualism delivered by many cognitive neuroscientists [9]. Moreover, the resistance persists despite the recognition by many psychologists that emotion often includes cognitive appraisal [10].

In this paper we concentrate on the pleasure that is obtained from satisfying curiosity or gaining knowledge, and seek a possible neural mechanism for that type of pleasure. The theory developed here will propose that curiosity-related pleasure has a neural substrate that is partly shared with and partly distinct from the substrate for other forms of pleasure.

## 2. PERCEPTUAL AND CONCEPTUAL PLEASURE

Biederman and his colleagues [11, 12] asked the same question about the source of informational pleasure. They started their inquiry in the perceptual domain:

Human beings are designed to be “infovores.” It’s a craving that begins with a simple preference for certain types of stimuli, then proceeds to more sophisticated levels of perception and cognition that draw on associations the brain makes with previous experiences. When the hunger becomes even moderately starved, boredom sets in. ([11], p. 247)

An fMRI experiment [12] tested participants viewing visual scenes that were either more or less preferred. The experimenters found that early stages of visual processing did not distinguish between the two classes of scenes. However, the more preferred scenes evoked greater blood-oxygen level dependent responses in the parahippocampal cortex (PHC), an area of high-level visual processing that codes contextual associations of visual stimuli. Notably the PHC is also an area with a high density of  $\mu$ -opioid receptors, which are involved in the feeling of pleasurable emotions. The cortical opioid signals may in turn increase dopamine activity in the ventral striatum, a key part of the system for activating behaviors leading to rewards. In fact Yue et al. [12] found that highly preferred images produced greater

activation than less preferred images in the ventral striatum as well as the PHC.

Biederman and Vessel [11] suggested that one key element of the desirability of visual scenes is novelty. The first presentation of a scene evoked more PHC activity than later presentations of the same scene. Yet novelty alone does not ensure desirability: the scenes also need to be rich in detail and in potential positive associations for the viewer.

The empirical evidence Biederman and his colleagues adduce for a knowledge instinct is visual. Yet without evidence they suggest that some form of their mechanism generalizes both to other senses such as audition and to the conceptual domain. To my knowledge there have not yet been fMRI studies bearing on the pleasure from other modalities of information processing. Yet there has been some behavioral evidence for a knowledge instinct in the conceptual domain.

### 3. PLEASURE FROM LEARNING NEW INFORMATION

Perlovsky, Bonniot-Cabanac, and Cabanac [5] investigated the pleasure that people feel from learning new information. The examples they used were general knowledge questions, such as “What is the meaning of the word ‘Huguenot’?” and “How do you bake bread?” These researchers found that the amount of self-reported pleasure their participants experienced when reading about factual information did not correlate with the newness of the information to them, but correlated strongly with their expressed curiosity to learn that information.

To my knowledge the curiosity about general knowledge has not been investigated with fMRI studies. There have been a large number of fMRI studies of semantic memory and reasoning, most of which have pointed to activity in different parts of association cortex, particularly prefrontal and temporal cortex (see, e.g., [13]). Is there a mechanism for pleasure from curiosity about new information that includes these areas of association cortex?

At this stage, analogies of conceptual pleasure with the visual pleasure mechanism of [11] and [12] must be speculative. The pathways for relationships of conceptual information to context, memory, and emotion are far less well mapped out than the analogous pathways for perceptual information. The PHC appears to be somewhat specialized for visual and spatial information, but is there an analogous cortical region that represents the emotional content of ideas and is rich in opioid receptors?

Emotional associations with cognitive entities typically engage the brain’s reward system which

includes orbitofrontal cortex (OFC) and ventral striatum [14], whether the rewards come from drugs or natural reinforcers. The connections to OFC from other prefrontal association areas are likely to mediate the emotional valuation of ideas and concepts. Studies of various forms of substance abuse disorders (e.g., [15]) have suggested considerable opioid activity in OFC that plays a role in impulsive or deliberate decision making. As in the theory discussed in [11], this opiate activity in turn should affect dopamine activity in the ventral striatum.

In order to build a neural network theory of curiosity and pleasure, we must also ask how (some) novel information comes to generate a pleasure that is less intense when the information has become well known. For the advantage of novel over established perceptual information, Biederman and Vessel [11] suggest a competitive learning mechanism, and competitive learning is likely to operate in the realm of ideas as well as the realm of percepts. In addition, though, the competition between ideas is always biased in various ways. Emotionally significant ideas have a competitive advantage, but so do novel ideas whose emotional significance has not yet been determined. The advantage of novelty is often modeled as a disadvantage of familiarity, due to habituation of well-worn pathways, the opposite of Hebbian learning whereby pathways are strengthened by repeated use. One widely used habituation mechanism is the gated dipole, whereby habituation is achieved by depletable chemical transmitters ([16, 17]).

Fig. 1 presents oversimplified but instructive modeling framework for generating pleasure from new knowledge. Primary representations of conceptual knowledge can be assumed to be located in various, primarily temporal and parietal, regions of association cortex [18]. These temporo-parietal representations, via intracortical connections, are combined with temporo-parietal representations of relationships among concepts (e.g., “IS A,” “HAS A,” “IS PART OF”) to form representations of ideas, as in a previous model of creative brainstorming [19]. The idea representations are then assumed to “lift” to both orbitofrontal and dorsolateral cortices.

At each of those two prefrontal areas the lifted concept representations are arranged in a field of gated dipoles (cf. [20] for an orbitofrontal-level dipole-based model of other data). In a dipole field [21], each entity is represented not by a single node but by a pair of “on” and “off” pathways. Using a mechanism of neurotransmitter depletion, the on or off pathway becomes transiently active (*rebound*) when there is a decrease of activity in the opposite pathway, which allows for counterfactual comparison

of valuations. Also the on channels within a gated dipole field compete via lateral inhibition, allowing representations that receive inputs from other brain regions (e.g., regions denoting either context or

emotional significance) to relatively dominate other representations.

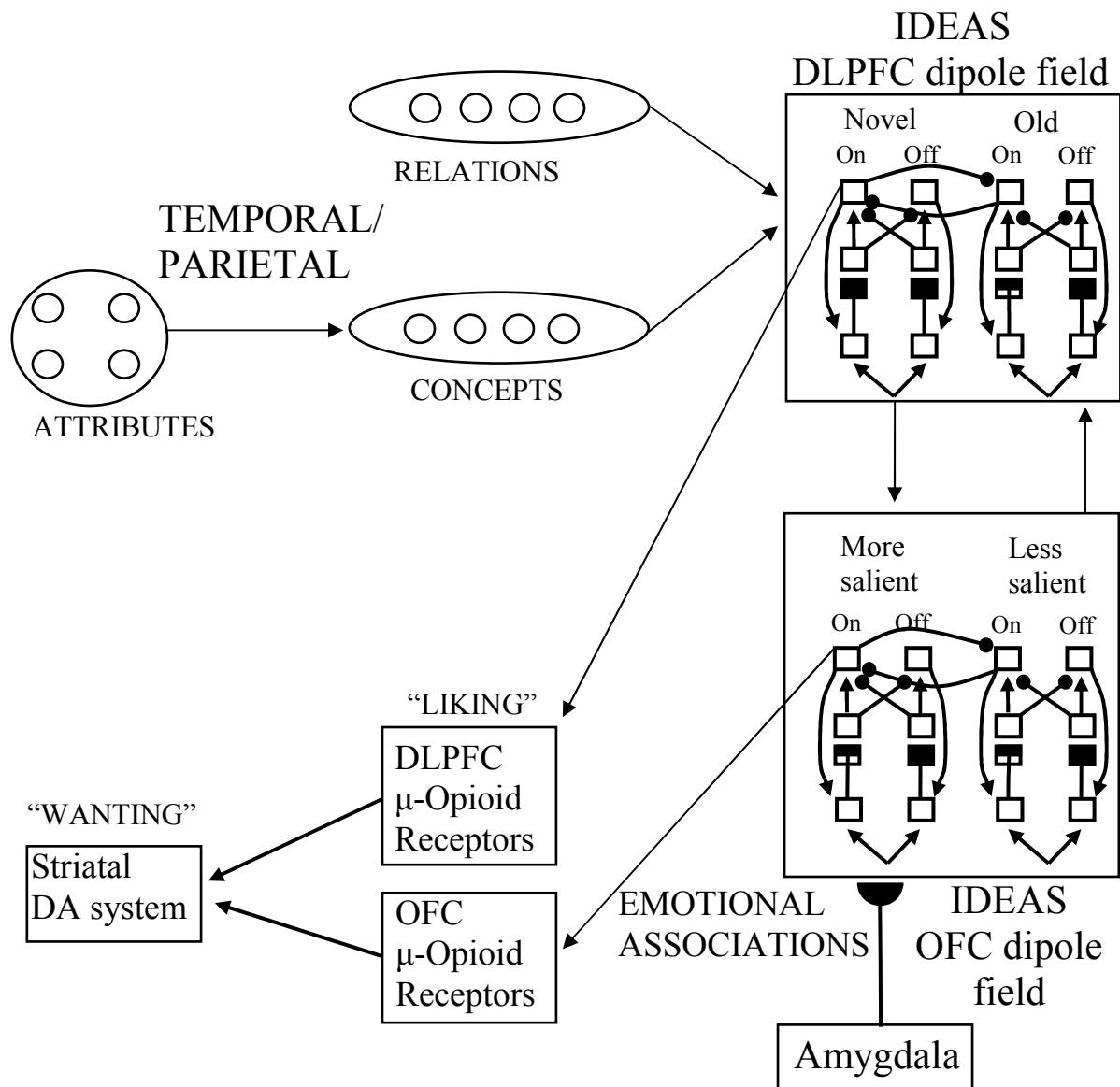


Fig. 1. Network for knowledge-based pleasure. “On” and “Off” refer to the two opposing pathways in a gated dipole. Arrows denote excitation, filled circles inhibition, and semicircles learning, filled or partially filled boxes depletable transmitter. There is competition between idea representations at the DLPFC and OFC, with winners accessing the  $\mu$ -opioid receptors. The competition is biased in favor of both novel and emotionally salient ideas. See the text for other explanations.

The dipole field at the orbitofrontal cortex can encode the relative affective pleasure associated with each possible option considered, whether it is a decision [18], a percept [11], or a concept [5]. This dipole field also has feedback connections with the corresponding dipole field at the dorsolateral prefrontal cortex, which can

more accurately than anywhere else in the brain include the truth or falsity of informational statements. Both prefrontal loci contain  $\mu$ -opioid receptors [15], and a combination of the opioid receptors in both regions can code the informational pleasure from gaining new and accurate knowledge. We suggest that the

dorsolateral involvement makes this pleasure somewhat different from the pleasure generated by more primary reinforcers such as good food or good sex, whereas the orbitofrontal involvement means that knowledge-based pleasure has some similarity to other forms of pleasure.

In turn these opioid receptors influence activity in the ventral striatum. At the ventral striatum it is the dopamine receptors that get involved in the process, mediating incentive motivation toward actions that increase the likelihood of obtaining rewards [22]. Many behavioral neuroscientists [23, 24] have made the distinction between the role of dopamine in “wanting” (that is, incentive salience) and the role of opioids in “liking” (that is, positive hedonic feelings)

#### 4. SUMMARY

The rich interconnections between the cognitive processing and emotional expression systems in the brain lead to a wide variety of cognitive-emotional interactions that are yet just barely understood. Rather than being opposites, emotion and cognition are partners in the process of living in and making sense of the environment.

One of these interactions involves the pleasurable emotions, some of them related to aesthetics and some to a feeling of security from understanding, that arise from acquiring new knowledge. This pleasure can be modeled through the network of Figure 1, which includes both Hebbian and anti-Hebbian learning and analogs of semantic association cortex, orbitofrontal cortex, ventral striatum, and both opioid and dopamine receptors.

The network of Fig. 1 is far from complete, in part because of the paucity of relevant experimental results on the phenomenon of curiosity-related pleasure. Also, there is much that is known about opioid receptors that is not shown in that figure. For example, it is known that there are also many opioid receptors in the basal ganglia and that there is interaction between the opioids in two “hot spots,” the ventral striatum and ventral pallidum [25]. Also, it is known that opioid neurons tend to be inhibitory and act on other inhibitory neurons that use GABA as a transmitter [11]. Hence the network is likely to undergo multiple revisions as more data become available. Yet the current network, building on existing models of other cognitive and emotional processes, is rich

enough to suggest a plausible brain mechanism whereby obtaining new knowledge might lead to pleasurable emotions.

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