

Frontotemporal and Dopaminergic Control of Idea Generation and Creative Drive

ALICE W. FLAHERTY*

Department of Neurology, Massachusetts General Hospital and Harvard Medical School,
Boston, Massachusetts 02114

ABSTRACT

This article presents a three-factor anatomical model of human idea generation and creative drive, focusing on interactions between the temporal lobes, frontal lobes, and limbic system. Evidence is drawn from functional imaging, drug studies, and lesion analysis. Temporal lobe changes, as in hypergraphia, often increase idea generation, sometimes at the expense of quality. Frontal lobe deficits may decrease idea generation, in part because of rigid judgments about an idea's worth. These phenomena are clearest in verbal creativity, and roughly parallel the pressured communication of temporal lobe epilepsy, mania, and Wernicke's aphasia—compared to the sparse speech and cognitive inflexibility of depression, Broca's aphasia, and other frontal lobe lesions. The phenomena also shape non-linguistic creativity, as in that of frontotemporal dementia. The appropriate balance between frontal and temporal activity is mediated by mutually inhibitory corticocortical interactions. Mesolimbic dopamine influences novelty seeking and creative drive. Dopamine agonists and antagonists have opposite effects on goal-directed behavior and hallucinations. Creative drive is not identical to skill—the latter depends more on neocortical association areas. However, drive correlates better with successful creative output than skill does. Traditional neuroscientific models of creativity, such as the left brain – right brain hemispheric model, emphasize skills primarily, and stress art and musical skill at the expense of language and mathematics. The three-factor model proposed here predicts findings in a broad range of normal and pathological states and can be tested in many experimental paradigms. *J. Comp. Neurol.* 493:147–153, 2005. © 2005 Wiley-Liss, Inc.

Indexing terms: frontal lobe; temporal lobe; hypergraphia; bipolar disorder; dopamine; motivation

Creativity has been essential to the development of human civilization, and thus of neuroscience. Neuroscientists have nonetheless been hesitant to study creativity, distrusting its animal models and perceiving it as difficult to quantify even in humans. Anatomical and physiological understanding of the phenomenon is growing, however. For the purposes of this article, a creative idea will be defined simply as one that is both novel and useful (or influential) in a particular social setting (Perkins, 1988; Csikszentmihalyi, 1999). The definition captures the cultural relativity of creativity (using a lever to move a rock might be judged novel in a Cro-Magnon civilization, but not in a modern one), and it also captures the distinction between the creative and the merely eccentric or mentally ill (novelty without utility).

Based on a psychometric approach to novel idea generation (Guilford, 1950), there now exist behavioral tests of creativity with both interrater reliability and predictability for future performance (Cromptley, 2000; Carson et al., 2005). Psychometric studies complement developmental

approaches (Sawyer et al., 2003) and historiometric analyses of the lives of eminent creators (Gardner, 1993). All have provided new support for the age-old theory that creativity is associated with psychopathology, most often hypomanic or mildly psychotic personality traits without full-blown illness (Andreasen, 1987; Jamison, 1989). However, the neurobiology linking these personality traits to creativity is unclear.

The last influential neuroscientific theory of creativity was the hemispheric lateralization model that grew in the

Grant sponsor: National Institutes of Health; Grant number: K08 NS02067-01; Grant sponsor: Claffin Distinguished Scholar Award, Radcliffe Institute for Advanced Study.

*Correspondence to: Alice W. Flaherty, VBK 905B, Massachusetts General Hospital, 55 Fruit St., Boston, MA 02114. E-mail: aflaherty@partners.org

Received 8 June 2005; Revised 25 July 2005; Accepted 1 August 2005

DOI 10.1002/cne.20768

Published online in Wiley InterScience (www.interscience.wiley.com).

1970s from studies of patients who had had corpus callosotomies for epilepsy (Bogen and Bogen, 1988; Hoppe, 1988). Researchers postulated that the nondominant hemisphere is specialized for creative activity such as holistic pattern recognition, art, and music. That lateralization model applies poorly to language-based innovation. This is a significant defect, since symbolic verbal communication underlies most creative thought and its cultural transmission—and may have driven the evolutionary increase in the size of the human brain (Diamond, 1995). The lateralization model's exaggerated emphasis on the nondominant hemisphere was tempered by later evidence that maximizing the function of both hemispheres is probably more important than selectively activating the right hemisphere (Martindale, 1999). Moreover, right or left hemisphere lesions rarely affect creativity selectively; their effect is always clouded by their profound impairment of more general skills.

The model of creative idea generation presented here differs in four ways from the hemispheric model. First, although the model does not turn the lateralization theory completely on its head, it turns the axis by 90 degrees, arguing that connections between the frontal lobes and temporal lobes are more important than those between left and right hemispheres. Second, it incorporates the role of the limbic system in generating this drive. Most neuroscientific studies of language have focused on skill, but the limbic drive to communicate is neurally independent of the skill to do so, and probably more important for creativity. Third, the model focuses on aspects of creativity that are relatively independent of domain. In particular, it applies to idea generation using language and mathematics, as well as artistic and musical composition. Fourth, it predicts a wider range of findings in normal subjects, drug-treated ones, and in patients with a variety of lesions, rather than solely in surgically treated epileptics. Although not all aspects of this model have yet been tested, they are testable. Thus, they make it clearer that creativity can and should be a phenomenon worthy of scientific study.

TEMPORAL LOBES AND IDEA GENERATION

The neurological phenomenon of hypergraphia, a compulsive drive to write, helps anatomically characterize creative drive. It was first localized in some temporal lobe epileptics (Waxman and Geschwind, 1974). Hypergraphia is generally proposed to reflect decreases of temporal lobe activity. It is most common when the lesion is in the right hemisphere, perhaps because the left, language-dominant side is then disinhibited (Yamadori et al., 1986).

Temporal lobe epilepsy is not the only brain condition that produces hypergraphia; indeed, most patients with hypergraphia have mania and related states of agitation (Kraepelin, 1921). Manic patients show a resting state increase in right anterior temporal SPECT signal and decrease in lower left temporal quantitative EEG (Gyulai et al., 1997; Small et al., 1998). Behavioral activation paradigms have produced more complicated, task-dependent activation patterns (Haldane and Frangou, 2004). Temporal lobe lesions, especially on the right, are the most likely lobar lesions to generate mania (Braun et al., 1999). When frontal lesions occasionally produce mania or pseudomanic disinhibition, PET scans also show

altered temporal lobe activity (Starkstein et al., 1990). Manic hypergraphia and pressured speech reflect underlying idea pressure and loose, cross-modal associations that are, when the manic state is mild enough not to be disabling, significantly associated not only with novel ideas but with socioeconomic success (Coryell et al., 1989).

While the correlation between manic states and creativity is strongest for language-based fields, temporal lobe changes can also produce the equivalent of hypergraphia in other creative fields. Frontotemporal dementia is the best-known example. A subset of these patients has neurodegeneration that selectively affects the temporal lobe. Up to 10% of that subset develops compulsive artistic or musical interests, even when they had no preexisting artistic tendencies (Miller et al., 1998).

Other conditions that both affect the temporal lobe and increase creative drive are listed in Table 1. Notably, left temporal lobe lesions in or near Wernicke's area can increase speech output, even though they produce deficits in understanding speech. Such pressured speech in part reflects the fact that the patient's speech is not inhibited by comprehension of his/her errors. The model proposed here allows rephrasing the mechanism of increased speech output in anatomical terms. Because temporal lobe activity inhibits the frontal lobe (Menzel et al., 1998), speech output increases when the temporal lobe speech comprehension area no longer inhibits the frontal lobe speech generation area. Right hemisphere lesions, which do not impair comprehension in left-dominant patients, and can disinhibit left hemisphere language function, are the most likely of all brain regions to trigger pressured speech (Braun et al., 2004).

Is the temporal lobe, then, the seat of creativity? The data above suggest that it might equally be described as the seat of creativity suppression, since most of the temporal lobe conditions known to trigger creative drive seem to disrupt temporal lobe function. The relative contributions of lateral temporal cortical areas and the medial, amygdalohippocampal system may not be equal, however. Wernicke's speech area needs to function for successful linguistic creativity. Bipolar disorder, the disorder best correlated with successful creativity, is associated with left or bilateral amygdala enlargement (Haldane and Frangou, 2004). The relative absence of hippocampal atrophy may explain the cognitive sparing in manic depression compared with schizophrenia, the latter disorder being much less correlated with creativity. Alterations in amygdalar function, in assigning emotional meaning or affective valence to events or ideas, may underlie the idiosyncratic passionate interests of manic patients. Although in most cases their pursuits are misguided or overly risky, in mild bipolar disorder they can be turned to creative use.

LIMBIC SYSTEM DOPAMINE AND THE RELATION BETWEEN DRIVE AND SKILL

Hypergraphia reflects a drive to write, not always writing skill. Although a few great writers such as Dostoevsky were thought to have epileptic hypergraphia, many hypergraphic writers merely write interminable office memos, or make lists of their favorite songs. Nonetheless, creative drive can secondarily improve creative skill. One way is a practice effect: the more subjects write or paint, the better they get at doing so. A second way, proposed as the Dar-

TABLE 1. Conditions in Which Altered Creative Outputs Are Associated with Temporal, Limbic, and Frontal Changes

Condition	Behavioral change	Physiological evidence
<i>Temporal Lobe</i>		
Temporal lobe epilepsy	Hypergraphia, viscosity	EEG, MRI, PET, lesion studies
Hypo/mania, mixed states	Pressured speech & writing; muse experiences	fMRI, EEG, PET
Wernicke's aphasia	Pressured, empty speech; no insight	Lesion studies
Other temporal lobe lesions	Hypomania and mania	Lesion studies
Frontotemporal dementia	Pressured artistic and musical expression	SPECT, PET, MRI, fMRI
Command hallucinations	Auditory hallucinations/muse experiences	fMRI, TMS
Metaphorical thinking	Tendency to analogies, associative thinking	Lesion studies
<i>Limbic / Dopaminergic</i>		
Levodopa, DA agonists	High productivity/drive, lower latent inhibition	Drug studies, PET receptor binding
DA antagonists	Decreased drives and creativity	Patient reports, receptor binding studies
Psychosis	Hallucinations/muse experiences	DA agonists cause, antagonists treat
Psychostimulant use	High productivity/punding, lower latent inhibition	Drug studies, PET receptor binding
Nonspecific arousal	Exercise, phototherapy, and Mozart effect raise creativity	
<i>Frontal Lobe</i>		
Depression	Self-critical; low energy inhibits work	fMRI, PET, lesion studies
Anxiety	Self-critical; "stage fright" inhibits work	fMRI, PET, lesion studies
Broca's aphasia	Speech production deficit, with insight	Lesion analysis
Other frontal lobe lesions	Abulic mutism, perseveration, solution fix	Lesion analysis
Normal/creative subjects	Tests of idea fluency	fMRI
Writers/musicians cramp	Focal dystonia from stressed practice	fMRI, PET
Metonymical thinking	Thought based on spatial/temporal sequence	Frontal lesions, depression, block
Antidepressants	Improve depression and secondary block	fMRI, PET
Electromagnetic stimulation	Increased productivity, creativity	DBS, TMS

DA, dopamine; EEG, electroencephalogram; fMRI, functional MRI; PET, positron emission tomography; SPECT, single photon emission computed tomography; TMS, transcranial magnetic stimulation

winian theory of creativity, depends on a Gaussian distribution of the idea quality generated by a subject (Simonton, 1999). When high motivation increases the number of ideas produced, the number of novel and useful ideas increases proportionately. The common strategy of brainstorming attempts to take advantage of this phenomenon. The Darwinian model predicts that the subjects generating the best ideas will on average also be the most driven and productive, and that innate skill will be less relevant. Indeed, there is substantial evidence that creativity is essentially independent of I.Q. above about 115 (Sternberg and O'Hara, 1999). Above this threshold, the model predicts that brain motivational systems will be more relevant than networks primarily subserving skill.

Creative subjects have higher baseline levels of arousal and greater response to sensory stimulation (Martindale, 1999). Dopamine decreases latent inhibition, a behavioral

index of the ability to habituate to sensations (Ellenbroek et al., 1996; Swerdlow et al., 2003). Low latent inhibition can flood an organism with stimuli, and is seen in psychosis (Swerdlow et al., 1996). But low latent inhibition is also characteristic of creative individuals with high intelligence (Carson et al., 2003). It may be that highly intelligent subjects can find patterns in what would otherwise be a disorienting barrage of sense data.

Dopamine does not merely raise baseline arousal. The focused aspect of creative arousal, its high goal-directedness, may be driven by mesolimbic dopaminergic activity (see Fig. 1). Dopamine mediates reward-seeking activity ranging from gambling and cocaine addiction to the appreciation of beautiful faces and music (Aharon et al., 2001; Breiter et al., 2001). It can trigger the drive to communicate (Wintink and Brudzynski, 2001), although too much dopaminergic activity may cause stuttering or

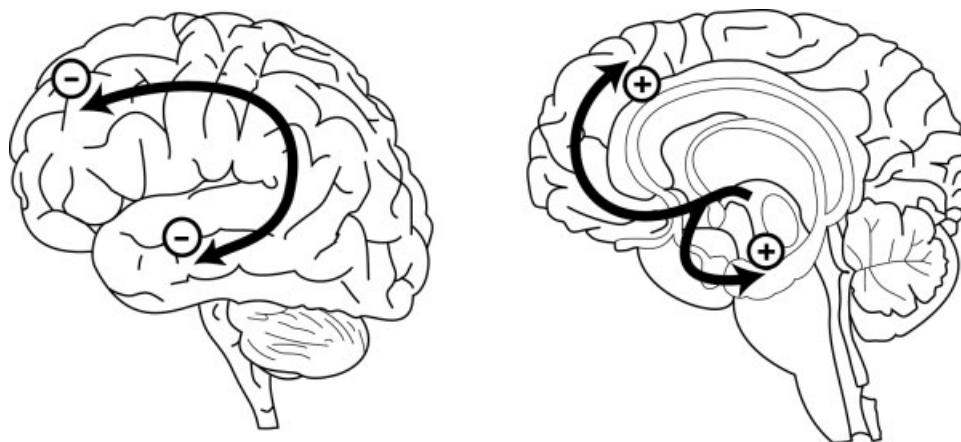


Fig. 1. Sketch of the brain pathways involved in creative drive. **A:** The left lateral surface view of the brain shows corticocortical connections between the frontal and temporal lobes. To a first approximation, their net effect is mutually inhibitory. **B:** The right, medial surface shows mesolimbic dopaminergic projections. They may facilitate creativity through driving goal-directed behavior and decreasing latent inhibition.

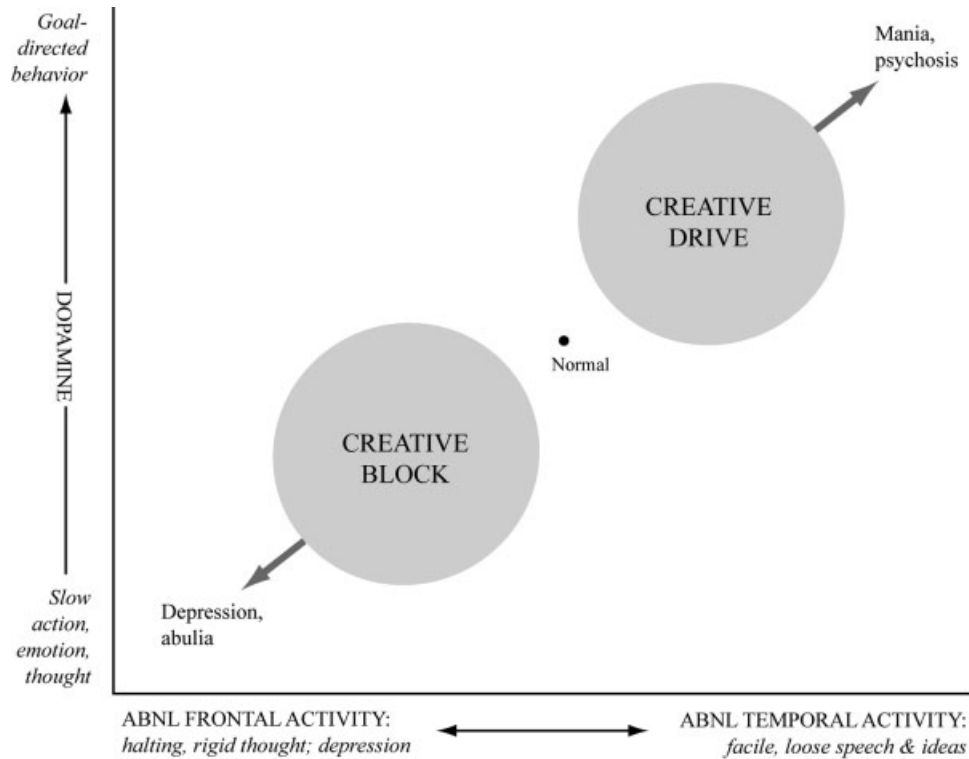


Fig. 2. Graphical representation of interactions between frontal, temporal, and dopaminergic systems in idea generation. Creative drive increases with abnormalities of temporal lobe function and increasing dopaminergic tone. Creative block increases with abnormalities of frontal lobe activity, or decreasing dopaminergic tone.

coprolalia. High doses of levodopa can cause excessively focused, highly complex motor stereotypies, such as repeatedly disassembling and reassembling a motorcycle engine (Fernandez and Friedman, 1999). Whereas dopamine agonists can induce hypomania and hallucinations (Peet and Peters, 1995), the dopamine antagonists, generally used as antipsychotics, are notorious for their ability to suppress not only hallucinations and stereotypies but also the free associations underlying creativity.

One possible mechanism for dopamine's role in focused reward-seeking behavior is a center-surround inhibition model (Mink, 1996). In this scheme, dopamine facilitates voluntary, goal-directed activity and inhibits competing behaviors. In the motor rather than cognitive system, the balance between these two poles may explain motor phenomena such as dystonia and tics (Mink, 2003). Dopamine clearly drives center-surround inhibition in sensory systems such as the retina (Bodis-Wollner and Tzelepi, 1998). Dopamine may also play a role in creative discovery through its effect on novelty-seeking. An allele of the D4 receptor has been postulated, somewhat controversially, to be a novelty-seeking gene (Keltikangas-Jarvinen et al., 2003; Savitz and Ramesar, 2004).

The temporal lobe plays a role in this interaction between limbic dopamine, novel creative thought, and novel thought that is merely psychotic. Functional MRI shows that schizophrenic auditory hallucinations—which can resemble the experience of having a creative idea dictated by the muse—selectively activate the temporal lobe (Shergill

et al., 2001). Metaphoric, cross-modal thought is selectively impaired by temporal lobe lesions (Jakobson and Halle, 1972). Although metaphors, when vivid enough, can be a step along the psychotic spectrum towards delusion (“I suffer like Jesus” becomes “I am Jesus”), metaphoric thought is nonetheless vital for creativity because metaphor depends on detecting analogies between phenomena previously thought unrelated. This is as true for non-literary creativity as for writers. Even scientific models are metaphors, ones tight enough to allow predictive power (Martindale, 1999).

FRONTAL LOBE AND CREATIVE BLOCK

A much more common complaint than excessive creative drive is its lack. Is creative block caused by an increase in temporal lobe activity, and creative drive caused by its decrease? Probably not. There seems to be a better correlation between frontal lobe malfunction and creative block (see Fig. 2). Evidence comes from several conditions associated both with frontal lobe dysfunction and with creative block (see Table 1). Since the frontal and temporal lobes are to a first approximation mutually inhibitory, creative block and pressured output do not usually occur together. They can, however—as in the highly repetitive hypergraphia of some epileptics.

The first condition linking frontal dysfunction and block is depression. Many techniques, including functional brain imaging and lesion analysis, have demonstrated frontal deficits in depression. During depression, motiva-

TABLE 2. Relation between States of Creative Drive, Aphasias, Mood States, and Lesion Locations

	Wernicke's aphasia	Hypergraphia	Broca's aphasia	Writer's block
Linguistic output	↑	↑	↓	↓
Awareness of deficit	↓	↓	↑	↑
Depression & anxiety			↑	↑
Mania, irritability	↑	↑		
Location of lesion	Temporal lobe	Temporal lobe	Frontal lobe	Frontal lobe?

tion and cognitive flexibility decrease, as do goal-directed activities such as eating and sex. Although creative subjects paradoxically more often have a history of depression than the average, their creative work is not done during their depressions, but in rebound periods of increased energy between depressions (Jamison, 1989; Flaherty, 2004).

When depression is treated, frontal lobe function normalizes on functional imaging (Goldapple et al., 2004). Creative block usually improves as normal levels of motivation return—with the caveat that side effects such as mood flattening or agitation from antidepressants can be counterproductive. Stimulants can help depression, as well as creativity, as described above. Nonpharmacologic treatments of depression such as exercise and phototherapy may help creativity and productivity even in blocked subjects with no signs of depression (Norden and Avery, 1993; Steinberg et al., 1997).

The second frontal lobe condition similar to creative block—especially writer's block—is a lesion in Broca's area. Broca's lesions produce a selective deficit in speech production, in contrast to the speech comprehension problems of Wernicke's aphasia. Although writer's block is not an aphasia or agraphia, it shares with Broca's aphasia such features as painfully retained awareness of speech errors, as well as the decreased linguistic output. This awareness causes frustration and depressed mood that further inhibit speech. Table 2 shows the parallels between Broca's aphasia and block, and Wernicke's aphasia and hypergraphia.

A third group of conditions, frontal lesions outside Broca's area, can cause depression and decreased speech output independent of aphasia. Frontal lobe lesions can cause cognitive deficits such as perseveration that are similar to the dogged and unproductive efforts of blocked writers. Both appear to respond to sudden environmental changes—blocked subjects can escape their mental ruts when distracted by a break from the problem.

Anxiety is a fourth condition that, like depression, shows frontal lobe changes in a number of paradigms (Cannistraro and Rauch, 2003), and anxiety is highly associated with creative block. Block of this form, which resembles performance anxiety, should respond to antidepressants just as anxiety does. Arousal levels are higher in anxiety than depression, however, so stimulants can be counterproductive. This reflects the Yerkes-Dodson law that task performance is an inverted U-shaped function of arousal level. Anxiety states exceed the ideal arousal for task performance. Task performance has a similar inverted U-shaped relationship to the beneficial cognitive effects of dopamine agonists (Kimberg et al., 2001).

Fifth, features of writer's cramp—a focal dystonia that shows changes in sensorimotor and premotor cortex activity (Lehericy et al., 2003)—suggest that it may be a more motor, posterior frontal analog of writer's block. Writer's cramp, like block, appears to be induced by highly attended, repetitive, stressed practice of the task. Continued attempts to write often only worsen the cramp, whereas enforced inactivity—like the breaks that help perseveration and block—can sometimes be therapeutic (Byl et al., 1996).

Sixth, electromagnetic studies demonstrate that the functioning frontal lobe stimulates creativity. When subjects with high and low creativity are compared, the former have both higher baseline frontal lobe activity and greater frontal increase while performing creative tasks (Carlsson et al., 2000). There is preliminary evidence that transcranial magnetic stimulation over frontal lobes can increase creativity in normal subjects during both drawing and writing tasks (Snyder et al., 2004). There are case reports of patients whose creativity increased after receiving subcortical deep brain stimulating electrodes near the nucleus accumbens (Gabriels et al., 2003; Flaherty et al., 2005). The accumbens' connections to the frontal and temporal lobes, and its role in limbic generation of drives, may help explain this effect.

Relative contributions to creativity from the temporal and frontal lobes may in part reflect the distinction between what is variously described as divergent versus convergent thought, primary versus secondary process thought, or the writing versus editing stages (Flaherty, 2004). What about relative contributions to idea generation from different frontal subsystems? Lesions of medial prefrontal cortex can produce amotivational, abulic states of decreased creative drive. Dorsolateral prefrontal cortex's importance for working memory and flexible problem-solving suggests a greater role in creative skill than in drive. Motor and premotor cortex are probably more necessary for performance than for conception of a creative plan. While lesions of all of these systems would be detrimental to idea generation, orbitofrontal lesions may have a partly opposing effect, as they can produce disinhibition syndromes that at least superficially resemble mania.

SUMMARY

Overall, creative drive has the advantage of being an important but more tractable phenomenon than creativity itself. Creative drive's links to better-understood systems, such as the drive to communicate, provide both direct and indirect evidence for a three-factor anatomical model of creative drive coordinating frontal, temporal, and limbic systems. The frontotemporal interactions are probably mediated by mutually inhibitory corticocortical projections, whereas the limbic contribution is likely to be primarily dopaminergic.

These hypotheses are oversimplified. Because activation in the frontal and temporal lobes is mutually inhibitory only to a first approximation, a more accurate model than that presented in Figure 2 would require a three-dimensional plot in which frontal and temporal activation can vary independently. Much needs to be clarified about differential contributions from lateral and medial temporal subsystems, and from orbitofrontal, dorsolateral, and medial frontal regions. Nonetheless, testing the predic-

tions of the simple model proposed here may help characterize the role of these frontal and temporal subsystems, as well as permit direct comparison with older theories such as the hemispheric model of creativity. Doing so may prepare the way for the rigorous neuroscientific studies of creativity that are greatly needed.

LITERATURE CITED

- Aharon I, Etcoff N, Ariely D, Chabris CF, O'Connor E, Breiter HC. 2001. Beautiful faces have variable reward value: fMRI and behavioral evidence. *Neuron* 32:537–551.
- Andreasen NC. 1987. Creativity and mental illness: prevalence rates in writers and their first-degree relatives. *Am J Psychiatry* 144:1288–1292.
- Bodis-Wollner I, Tzelepi A. 1998. The push-pull action of dopamine on spatial tuning of the monkey retina: the effects of dopaminergic deficiency and selective D1 and D2 receptor ligands on the pattern electroretinogram. *Vision Res* 38:1479–1487.
- Bogen JE, Bogen GM. 1988. Creativity and the corpus callosum. *Psychiatr Clin North Am* 11:293–301.
- Braun CM, Larocque C, Daigneault S, Montour-Proulx I. 1999. Mania, pseudomania, depression, and pseudodepression resulting from focal unilateral cortical lesions. *Neuropsychiatry Neuropsychol Behav Neurol* 12:35–51.
- Braun CM, Dumont M, Duval J, Hamel-Hebert I. 2004. Speech rate as a sticky switch: a multiple lesion case analysis of mutism and hyperlalia. *Brain Lang* 89:243–252.
- Breiter HC, Aharon I, Kahneman D, Dale A, Shizgal P. 2001. Functional imaging of neural responses to expectancy and experience of monetary gains and losses. *Neuron* 30:619–639.
- Byl NN, Merzenich MM, Jenkins WM. 1996. A primate genesis model of focal dystonia and repetitive strain injury. I. Learning-induced dedifferentiation of the representation of the hand in the primary somatosensory cortex in adult monkeys. *Neurology* 47:508–520.
- Cannistraro PA, Rauch SL. 2003. Neural circuitry of anxiety: evidence from structural and functional neuroimaging studies. *Psychopharmacol Bull* 37:8–25.
- Carlsson I, Wendt PE, Risberg J. 2000. On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. *Neuropsychologia* 38:873–885.
- Carson SH, Peterson JB, Higgins DM. 2003. Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. *J Personal Soc Psychol* 85:499–506.
- Carson SH, Peterson JB, Higgins DM. 2005. Reliability, validity, and factor structure of the creative achievement questionnaire. *Creativ Res J* 17:37–50.
- Coryell W, Endicott J, Keller M, Andreasen N. 1989. Bipolar affective disorder and high achievement: a familial association. *Am J Psychiatry* 146:983–988.
- Cropley AJ. 2000. Defining and measuring creativity: are creativity tests worth using? *Roeper Rev* 23:72–79.
- Csikszentmihalyi M. 1999. Implications of a systems perspective for the study of creativity. In: Sternberg RJ, editor. *Handbook of creativity*. New York: Cambridge University Press. p 313–335.
- Diamond J. 1995. The evolution of human inventiveness. In: Murphy MP, O'Neill LAJ, editors. *What is life? The next fifty years: speculations on the future of biology*. New York: Cambridge University Press. p 41–55.
- Ellenbroek BA, Budde S, Cools AR. 1996. Prepulse inhibition and latent inhibition: the role of dopamine in the medial prefrontal cortex. *Neuroscience* 75:535–542.
- Fernandez HH, Friedman JH. 1999. Punding on L-dopa. *Mov Disord* 14: 836–838.
- Flaherty AW. 2004. *The midnight disease*. Boston: Houghton Mifflin.
- Flaherty AW, Williams ZM, Rauch S, Cosgrove GR, Eskandar EN. 2005. Deep brain stimulation of the anterior internal capsule for treatment of medically refractory Tourette syndrome. *J Neurol Neurosurg Psychiatry* (in press).
- Gabriels L, Cosyns P, Nuttin B, Demeulemeester H, Gybels J. 2003. Deep brain stimulation for treatment-refractory obsessive-compulsive disorder: psychopathological and neuropsychological outcome in three cases. *Acta Psychiatr Scand* 107:275–282.
- Gardner H. 1993. Seven creators of the modern era. In: Brockman J, editor. *Creativity*. New York: Simon & Schuster. p 28–47.
- Goldapple K, Segal Z, Garson C, Lau M, Bieling P, Kennedy S, Mayberg H. 2004. Modulation of cortical-limbic pathways in major depression: treatment-specific effects of cognitive behavior therapy. *Arch Gen Psychiatry* 61:34–41.
- Guilford JP. 1950. Creativity. *Am Psychol* 5:444–454.
- Gyulai L, Alavi A, Broich K, Reilley J, Ball WB, Whybrow PC. 1997. I-123 iofetamine single-photon computed emission tomography in rapid cycling bipolar disorder: a clinical study. *Biol Psychiatry* 41:152–161.
- Haldane M, Frangou S. 2004. New insights help define the pathophysiology of bipolar affective disorder: neuroimaging and neuropathology findings. *Prog Neuropsychopharmacol Biol Psychiatry* 28:943–960.
- Hoppe KD. 1988. Hemispheric specialization and creativity. *Psychiatr Clin North Am* 11:303–315.
- Jakobson R, Halle M. 1972. In: *Fundamentals of language*. Paris: Mouton.
- Jamison KR. 1989. Mood disorders and patterns of creativity in British writers and artists. *Psychiatry* 52:125–134.
- Keltikangas-Jarvinen L, Elovainio M, Kivimaki M, Lichtermann D, Ekelund J, Peltonen L. 2003. Association between the type 4 dopamine receptor gene polymorphism and novelty seeking. *Psychosom Med* 65: 471–476.
- Kimberg DY, Aguirre GK, Lease J, D'Esposito M. 2001. Cortical effects of bromocriptine, a D-2 dopamine receptor agonist, in human subjects, revealed by fMRI. *Hum Brain Mapp* 12:246–257.
- Kraepelin E. 1921. *Manic-depressive insanity and paranoia*. Edinburgh: Livingstone.
- Lehericy S, Meunier S, Garnero L, Vidailhet M. 2003. Dystonia: contributions of functional imaging and magnetoencephalography. *Rev Neurol (Paris)* 159:874–879.
- Martindale C. 1999. Biological bases of creativity. In: Sternberg RJ, editor. *Handbook of creativity*. New York: Cambridge University Press. p 137–152.
- Menzel C, Grunwald F, Klemm E, Ruhlmann J, Elger CE, Biersack HJ. 1998. Inhibitory effects of mesial temporal partial seizures onto frontal neocortical structures. *Acta Neurol Belg* 98:327–331.
- Miller BL, Cummings J, Mishkin F, Boone K, Prince F, Ponton M, Cotman C. 1998. Emergence of artistic talent in frontotemporal dementia. *Neurology* 51:978–982.
- Mink JW. 1996. The basal ganglia: focused selection and inhibition of competing motor programs. *Prog Neurobiol* 50:381–425.
- Mink JW. 2003. The basal ganglia and involuntary movements: impaired inhibition of competing motor patterns. *Arch Neurol* 60: 1365–1368.
- Norden MJ, Avery DH. 1993. A controlled study of dawn simulation in subsyndromal winter depression. *Acta Psychiatr Scand* 88:67–71.
- Peet M, Peters S. 1995. Drug-induced mania. *Drug Saf* 12:146–153.
- Perkins DN. 1988. Creativity and the quest for mechanism. In: Sternberg RJ, Smith EE, editors. *Psychology of human thought*. New York: Cambridge University Press. p 309–336.
- Savitz JB, Ramesar RS. 2004. Genetic variants implicated in personality: a review of the more promising candidates. *Am J Med Genet B Neuropsychiatr Genet* 131:20–32.
- Sawyer RK, John-Steiner V, Moran S, Sternberg RJ, Feldman DH, Nakamura J, Csikszentmihalyi M. 2003. *Creativity and development*. Oxford: Oxford University Press.
- Shergill SS, Cameron LA, Brammer MJ, Williams SC, Murray RM, McGuire PK. 2001. Modality specific neural correlates of auditory and somatic hallucinations. *J Neurol Neurosurg Psychiatry* 71:688–690.
- Simonton DK. 1999. *Origins of genius: Darwinian perspectives on creativity*. London: Oxford University Press.
- Small JG, Milstein V, Malloy FW, Klapper MH, Golay SJ, Medlock CE. 1998. Topographic EEG studies of mania. *Clin Electroencephalogr* 29:59–66.
- Snyder A, Bossomaier T, Mitchell DJ. 2004. Concept formation: “object” attributes dynamically inhibited from conscious awareness. *J Integr Neurosci* 3:31–46.
- Starkstein SE, Mayberg HS, Berthier ML, Fedoroff P, Price TR, Dannals RF, Wagner HN, Leiguarda R, Robinson RG. 1990. Mania after brain injury: neuroradiological and metabolic findings. *Ann Neurol* 27:652–659.

- Steinberg H, Sykes EA, Moss T, Lowery S, LeBoutillier N, Dewey A. 1997. Exercise enhances creativity independently of mood. *Br J Sports Med* 31:240–245.
- Sternberg RJ, O'Hara LA. 1999. Creativity and intelligence. In: Sternberg RJ, editor. *Handbook of creativity*. New York: Cambridge University Press. p 251–272.
- Swerdlow NR, Braff DL, Hartston H, Perry W, Geyer MA. 1996. Latent inhibition in schizophrenia. *Schizophr Res* 20:91–103.
- Swerdlow NR, Stephany N, Wasserman LC, Talledo J, Sharp R, Auerbach PP. 2003. Dopamine agonists disrupt visual latent inhibition in normal males using a within-subject paradigm. *Psychopharmacology (Berl)* 169:314–320.
- Waxman SG, Geschwind N. 1974. Hypergraphia in temporal lobe epilepsy. *Neurology* 24:629–636.
- Wintink AJ, Brudzynski SM. 2001. The related roles of dopamine and glutamate in the initiation of 50-kHz ultrasonic calls in adult rats. *Pharmacol Biochem Behav* 70:317–323.
- Yamadori A, Mori E, Tabuchi M, Kudo Y, Mitani Y. 1986. Hypergraphia: a right hemisphere syndrome. *J Neurol Neurosurg Psychiatry* 49:1160–1164.