Effects at the dendritic spine itself may modulate (inhibit) corticostriatal inputs onto spines also receiving a mesostriatal synapse, whereas those onto spines not receiving a mesostriatal synapse will be unaffected so that the pattern of corticostriatal input will be altered. The firing rate of the medium-sized spiny cells might also be reduced due to attenuation of tonic corticostriatal excitation via effects of the mesostriatal input onto spines and more generalized inhibition due to mesostriatal synapses onto dendritic shafts and cell bodies.

In electrophysiological studies on striatal cell firing rates in awake animals, Rolls *et al.* found that DA inhibited the basal firing rate without greatly affecting the increment of increased firing that occurred when a task (movement) was performed[4]. DA thus enhanced the detectability of signals arriving in the striatal neurones, so facilitating them. Much higher DA concentrations might inhibit firing to a greater extent, reducing all signal processing. Therefore, perhaps one effect of DA is to facilitate signal transmission at the medium-sized spiny cell via its effects on the basal firing rate of the cell by enhancing signal detectability. There may also be effects of the DA input to dendrites to affect the specific input pattern from the corticostriatal afferents. Effects of DA to enhance the efficacy of inputs to striatal neurones in rat brain at low concentrations but to inhibit responsiveness at higher concentrations have also been described in other studies[5]. The results of these studies provide mechanisms for apparent functional excitation and inhibition of striatal output cells by DA. The relative importance of excitation and inhibition in different cells could depend on the relative topography of DA inputs to different parts of the medium-sized spiny cell.

The other potential source of heterogeneity of the effects of DA is in the different DA receptor subtypes, D_1 and D_2, which have different biochemical effects at the cellular level. It has been suggested that the two receptor subtypes interact functionally in a complex manner[6] although both excitation and inhibition of striatal cells have been described, linked, respectively, to D_2 and D_1 receptors[7]. The relative distributions of the two subtypes are not known at the cellular level, but differential distributions of the two subtypes on different cells might account for heterogeneous functional effects.

Physiological studies have shown that the mesostriatal neurones fire rather slowly and that their activity increases slightly during and sometimes before a movement but not in any manner related to the details of a movement[8]. This suggests a modulatory role for this pathway rather than an executive one and is consistent with the nature of DA as a slow transmitter[9], and with the ability to replace, in part, defective mesostriatal function in Parkinson's disease with L-DOPA therapy.

Thus it seems that DA may, via its effects on the principal striatal output cells projecting to the medial globus pallidus and substantia nigra (pars reticulata), facilitate information flow in the corticostriato-thalamocortical circuits at the same time as altering the pattern of afferent information. Also, via inhibitory effects on the outputs to the lateral globus pallidus, DA regulates indirectly the activity in the subthalamic nucleus, which is thought to suppress unwanted movements.

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References

1 Albin, R. L., Young, A. B. and Penney, J. B. (1989) *Trends Neurosci.* 12, 366–375
2 Gerfen, C. R. (1988) *J. Electron Microsc. Tech.* 10, 265–281
3 Freund, T. F., Powell, J. F. and Smith, A. D. (1984) *Neuroscience* 13, 1189–1215
4 Rolls, E. T., Thorpe, S. J., Boytim, M., Szabo, I. and Perrett, D. I. (1984) *Neuroscience* 12, 1201–1212
5 Chiodo, L. and Berger, T. W. (1986) *Brain Res.* 375, 198–203
6 Waddington, J. L. and O'Boyle, K. M. (1987) *Rev. Neurosci.* 1, 157–184
7 Ohno, Y., Sasa, M. and Takaori, S. (1987) *Life Sci.* 40, 1937–1945
8 Schultz, W., Ruffieux, A. and Aebischer, P. (1983) *Exp. Brain Res.* 51, 377–387
9 Strange, P. G. (1988) *Biochem. J.* 249, 309–318

Reply

We are pleased that our article on the functional anatomy of basal ganglia disorders[1] has provoked discussion. Nonetheless, we believe that Barker has misinterpreted some aspects of our article.

The article is primarily concerned with explaining the pathophysiology of basal ganglia disorders and is not a comprehensive review of basal ganglia function. As such, we concentrated on motor aspects of basal ganglia function. However, we did mention that the thalamic target nuclei of the basal ganglia project to the whole prefrontal cortex. The concluding paragraph mentions the possible cognitive role of the basal ganglia and connections with limbic structures, including the amygdala. We certainly agree that the basal ganglia are likely to be involved in a wide variety of cognitive and motor processes. We believe that our attempt to explicate the functional anatomy of basal ganglia disorders casts light on normal basal ganglia function, and may indirectly help to explain the motor and non-motor function(s) of the basal ganglia.

Second, the available electrophysiological evidence indicates that the basal ganglia inhibit thalamocortical neurons[2,3].

Third, we did not suggest that the primary effect of dopamine on striatal neurons is inhibitory. An explicit and important feature of our model is that dopamine excites some subpopulations of striatal projection neurons while inhibiting others. Similarly, we do not believe that the striatonigral projection is of little importance in the genesis of movement disorders. Alterations in the function of all circuits of the basal ganglia must be considered in trying to explain the pathophysiology of movement disorders, and our

model incorporates changes in the behavior of the striatonigral projection.

Finally, our schematics are not intended to be a comprehensive review of basal ganglia connections. Rather, they illustrate how our model explains the functional anatomy of basal ganglia disorders. The cortico-subthalamic projection, like other important connections, was omitted in the interest of clear presentation, and not because we regard its role as trivial.

We agree with Strange that the differential excitatory/inhibitory effect of dopamine on striatal projection neuron subpopulations may be rooted in a complex interaction between mesostriatal terminal anatomy, the electrophysiological properties of striatal neurons, and the interplay of D_1 and D_2 receptors. We would add that D_1 and D_2 receptors probably have a heterogeneous cellular distribution within the striatum. Harrison *et al.* have recently shown that striatal D_1 receptors are preferentially located on striatonigral neurons[4].

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References

1 Albin, R. L., Young, A. B. and Penney, J. B. (1989) *Trends Neurosci.* 12, 366–375
2 Deniau, J. M. and Chevalier, G. (1985) *Brain Res.* 334, 227–233
3 Uno, M. and Yoshida, M. (1975) *Brain Res.* 99, 377–380
4 Harrison, M. B., Wiley, R. G. and Wooten, G. F. (1989) *Soc. Neurosci. Abstr.* 15, 585

reviews

Category-related recognition defects as a clue to the neural substrates of knowledge

Antonio R. Damasio

Circumscribed damage to human cerebral cortex can lead to a surprisingly selective breakdown of recognition. Patients may be unable to recognize a person's identity from their face, but retain the ability to recognize identity from gait, or they may experience a disproportionate difficulty in recognizing entities belonging to certain conceptual categories, such as natural kinds, and no difficulty in recognizing man-made items. The relation between such patterns of breakdown and the underlying damage to specific cortical regions suggests a possible organization for the neural substrates of knowledge, at the level of systems. In general, it appears that different neural systems are dedicated to the processing of certain characteristics of entities and events, in certain knowledge domains, but that systems are not dedicated to the representation of particular conceptual categories.

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In patients with selective damage to the cerebral cortex, recognition can break down in relation to intuitively separable compartments of knowledge. Aphasia has long been a paradigmatic example. Aphasic patients may become unable to recognize the meaning of some words, although still able to recognize the entities (e.g. individuals or objects), actions and events that the words denote. In some instances even the acoustical or visual structure of words can no longer be recognized. Recent studies have revealed that recognition may be disturbed for even more circumscribed fields of knowledge. Striking dissociations have been demonstrated, for example between the preserved ability to recognize facial expressions and the impaired recognition of facial identity[1], and between the preserved ability to recognize a person by means of their gait and the impaired ability to recognize their faces[2]. The recognition of 'natural' kinds such as animals seems to be more impaired than the recognition of man-made objects[3–8]. These surprising dissociations can be correlated with specific sites of damage in human neural systems, and the ensuing information used to hypothesize neural networks subserving learning and memory for different types and levels of knowledge[9–11].

Category-related recognition defects following focal brain lesions

At first glance, the recently described breakdowns of recognition seem to respect the boundaries of conceptual–lexical categories. A conceptual–lexical category is a collection of entities that share a distinctive set of characteristics, e.g. certain physical attributes, function, value to the perceiver, and so on, and that is denoted by a name tag. Let us begin by reviewing the available evidence briefly, drawing on the most complete documentation of these defects, which comes from patients with amnesia or visual agnosia.

Dissociated levels of face recognition

It has long been known that patients with face agnosia (a condition that generally follows bilateral lesions in ventral occipital and temporal association cortices) fail to recognize identity on the basis of a face but can glean the person's identity from the voice. An additional dissociation was reported by Damasio *et al.*[2], who noted that such patients could identify someone from the visual characteristics of their gait and posture. In other words, they cannot only properly derive identity from sound, but they can also do it on the basis of visual information other than faces. These findings underscore the fact that an entity (e.g. a given individual or object) generates a multiplicity of representations *within* the sensory cortices of the same modality (for vision, examples are shape, color, texture, motion) and *across* cortices of other sensory modalities (e.g. auditory, somatosensory, olfactory). Sets of pertinently linked records can be triggered from *any* of those representations, that is, a shared pool of memoranda can be activated by *any* stimulus (e.g. gait, posture, face itself, voice) that stands for an individual[11]. The set of recalled coevocations that define the meaning of an entity, and on

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