Basal Ganglia, Cingular Gyrus and Frontal Lobe

By Jerome Liss

A New Frontier of Science

Neurophysiological research regarding the brain is opening up new visions regarding human consciousness, the unconscious, emotions and so on. We are just at the beginning of this new field of inquiry. We can expect, over time, that methods of directly observing brain processes (such as Neuroimaging) will become more refined, and that the types of experience and behaviour under study will become more pertinent to real life. For the moment, the studies are limited to subjects responding to cognitive tasks or looking at emotionally provocative photos of unknown people. But it is expected that researchers will soon begin **to investigate experiential phenomena that are closer to real life situations**, despite the obvious limitation that the Subject must be put into a special apparatus (for example, during Positron Emission Tomography) that prevents observations in the "natural system" of daily life at home.

Vertical Processes in the Brain

A fundamental assumption of mind-body correlation is accepted almost universally in today's neurophysiological research: Consciousness is a result of processes within the cerebral **cortex!** But the story does not stop there. The cerebral cortex is continuously receiving messages, directly and indirectly, from the brain's lower levels: 1. From **sub-cortical** centers such as the amygdala, hippocampus, and basal ganglia. 2. From still lower levels such as the hypothalamus and central gray matter. 3. From yet lower nuclei located in the **brain stem** (meaning the pons and medulla): tegmentum, locus coeruleus, raphe nuclei, pendulo-pontine nuclei, all involved in neuromodulator production; and from the solitary nucleus and dorsal motor nucleus of the vagus, that connect the brain to the gastrointestinal tract. Thus cortical processes of the brain are riding on top of multiple sub-cortical and lower brain processes, much like **the foam riding on top of a wave**.

What is the point? **Conscious processes** at the brain's cortical level, are being continuously modified by **non-conscious processes** that take place at the brain sub-cortical and brain stem levels. If we say that the cortex is the "top" of the brain and the other regions are "lower down," we have a brain architecture that is "vertical." Thus, we are talking about "vertical neural processes." Studies by today's foremost neurophysiologists – Edelman, Rolls, Damasio, LeDoux, Heilman, Valenstein, to name but several – have been revealing a multitude of "vertical processes" that are relevant to consciousness, behaviour and emotion.

The Illusion that Our Consciousness is Self-Generating

The paradox is that we do not **experience** these vertical processes! It seems that mental changes are based on horizontal processes all occurring within the **cortex**. Put in experiential language: Our conscious experience seems complete, total, a single unity. ***"I know everything I experience."*** Therefore, when our consciousness establishes a sequence of conscious ideas -- "One idea leads to another" – it seems that we know what creates this sequence. "I'm in charge of my mind. I know what makes me think this way. I can change the direction of my thinking whenever I wish." The nature of consciousness is to induce this sense of unity and totality. Gerald Edelman, in **Wider than the Sky,** reiterates this same point: "Consciousness is a unitary phenomnena." (p.)

Let us translate this idea into neurophysiological terms: Consciousness makes us feel that our mental life is based exclusively on **horizontal** cortical-to-cortical (conscious) sequences. ***"I am what I think!"*** But research involving the brain's **vertical** processes shows that is not the case. It is only a mental illusion based on the unifying tendency of consciousness. What is really happening is that cortically-based conscious ideas make **reciprocal connections** with the sub-cortical non-conscious centers. This is based on the phenomena called "re-entry," (Edelman's important theoretical contribution.) "Re-entry" means that, on the one hand, the lower sub-cortical centers (non-conscious processes) receive messages from the cortical process (only some of which are "conscious"). And, on the other hand, these sub-cortical processes send messages back up to the conscious cortex. Result? The cortical processes that underly conscious ideas become modified by the non-conscious processes of the sub-cortex. And the experiential feeling, "I know **why** I'm thinking in this way, or having this thought," is an illusion.

What does this new mapping of the brain force us, perhaps reluctantly, to understand? "More is happening than what we know in our conscious experience." **Our neuronal mind is much larger than our conscious mind**.

In summary, non-conscious messages from the brain are stimulated by our mental processes and then modify, in turn, these same mental processes. And what do these non-conscious processes do? How do they affect our ongoing thoughts, emotions, attitudes, intentions, and so on?

For the moment, we can only give very tentative hypotheses. But we can expect that over the coming years our brain research methods will become more incisive, both at the level of registering specific cortical and sub-cortical phenomena, and also at the level of studying the experimental Subject's real life experience. As Philosopher of Science, Carl Hempel, points out, the ultimate goal of scientific investigation is to study "natural systems."

Clinical Hypotheses Based on Neurophysiology

A possible objection: Strict scientists might find the following sections that present **hypothetical correlations between sub-cortical processes and their influences upon consciousness** rather premature. Our knowledge in this field is still too fragmentary. Nevertheless, I propose the following justification: It is easier to modify and correct a primitive mapping of functions, than begin from scratch where there is no pathway in view. But, I admit, not all scientific thinking would agree with this approach.

Amygdala Emotions Spread Out in All Directions

1. The sub-cortical amygdala can influence our conscious experience of emotions. This is already proposed by Joseph LeDoux, who has extensively studied amygdala functions and its input-output connections with other brain areas. (See the article, "   ", for a specific proposal regarding the upward (conscious), horizontal (behavioural) and downward (autonomic) effects of amygdala processes.) **Rif.**

The amygdala has more indirect connections with the cortex, especially by way of the cingular gyrus, than direct connections. The final emotional experience, as in all conscious experiences, is a **distributed process** involving many cortical areas. But an essential area may be the orbito-frontal lobe. The medial frontal lobe may also come into play. Their position permits a direct interaction with the lateral frontal lobe, which receives messages of environmental input from the parietal lobe. Therefore we have a design well-suited, within the **frontal lobe**, to integrate the inner emotional life with the external environment.

Work by Antonio Damasio and Edmund Rolls offer more detailed maps of the frontal lobe architecture. This helps us understand the development of conscious "intention" and "goal creation" that then prepares us to take specific action. The final action component is transmitted directly to the motor cortex. But different parts of the frontal lobe also connect to the basal ganglia, the sub-cortical area important for specifying specific action

"routines." (From basal ganglia to thalamus to motor cortex, as Edelman shows.) In addition, since the cingular cortex also has strong connections to the basal ganglia, we have still another mode in which sub-cortical emotions, starting at the amygdala, can determine behaviour.
(From amygdala to cingular gyrus to basal ganglia.)
From Obsessive Repetition to Thought Sequencing

2. The basal ganglia influences our conscious motor actions: from basal ganglia to thalamus to motor cortex. (Edelman) Edelman also proposes that our thoughts may also be influenced by the sub-cortical basal ganglia. For one thing, the striatum, the first input level of the basal ganglia, has reciprocal connections with many of the cortical areas that give this first input to the basal ganglia. Perhaps this increases activation of these cortical areas, which might be experienced as heightened environmental perception (posterior lobe), memory recall (temporal lobe), generalized environmental mapping and calculations (parietal lobe), and goal-directed intentionality (frontal lobes).

It is also possible that the thalamic patterns, created by the basal ganglia output (from the substantia negra and globus pallidus), can also influence cortical patterns outside of the motor cortex. Thus, our **thinking** and other aspects of our mental life, once again, may be influenced by the sub-cortical basal ganglia. For example, it is possible that the **sequencing patterns of the basal ganglia motor routine** can then return to the cortex, via the thalamus, to **create sequencing of thoughts**, both verbal thoughts and non-verbal thoughts.

Let's take an example: On a clinical level, a person depressed, isolated and immobile, might have **a lack of "thought sequencing"** and return to his depressive ideation: a single negative thought of "I can't…" or "I'm no good…", etc. This negative **single-thought pattern** can be due to various factors: emotional, cognitive, memory, attitudinal, all involving different brain regions. It is possible, nevertheless, that an important determinant is the **action pattern** or, in this case, the lack of an action plan. In other words, the feeling of "helplessness," meaning, "There is nothing I can do…", may create a particular pattern of blocked action within the basal ganglia. The thalamus receives this particular blocked motor pattern and sends it up to the cortex, restimulating the cortical conscious component: "There is nothing I can do." (The emotional input from the amygdala would also be an essential part of this cognitive pattern.) We know, from clinical experience, that when the patient is helped to **act,** the depressive syndrome is partly relieved. Therefore, both the **emotional** amygdala and the basal ganglia **action** patterns can both contribute, on the one hand, to the pathology of depression and, on the other hand, to the overcoming of this pathology means of psychotherapy.

Sequencing in Thought and in Action

Let us carry this project of hypothesis-making yet further: Is it possible that "patterns of action" will then condition "patterns of thought." Daily life shows us that "hesitancy" and "uncertainty" in thinking can create "hesitancy" and "uncertainty" in action. (From parietal-frontal lobe "thought hesitancy" to "action hesitancy" involving cortical motor areas and the sub-cortical basal ganglia.)

"Re-entry," nevertheless, reminds us of the **reciprocity** of many brain processes. In this case we can hypothesize that **the action patterns of "hesitancy" and "uncertainty" can produce thinking that is likewise hesitant, uncertain, inconclusive, meandering, blocked, tangential, fragmented, dispersive, and so on.** These reciprocal mechanisms depend upon the same pathway: basal ganglia to thalamus to cortex. In fact, Edelman attributes the control of consciousness to this particular pathway, the thalamic-cortical circuit, and calls this the "core dynamic."

Movement and thinking in correspondence! A certain active individual goes from A to B in a straight line. That is also how he thinks.

Another active person circles about before facing his target directly. We can expect that his thinking will create the same form. "He seems to beat about the bush before getting to the essential point." These forms represent personality dynamics. Therefore, neurophysiological mapping of action-and-thought sequences can give us hypotheses for how the brain regulates personality.

An Interesting Sub-Cortical Phenomena: The Nucleus Accumbens

The Nucleus Accumbens receives inputs from cortical regions (Frontal Lobe, Cingular Gyrus) and from the sub-cortex (amygdala). Its major ouput is to the action-producing Basal Ganglia. Therefore, the N. Accumbens influences our "readiness" to act. Dopamine increases in the N. Accumbens (coming from the ventral tegmentum, a brain stem source of activating neuromodulators) is connected to the feeling of reward. The organism acts, feels good and is oriented.

This same region is involved in the pathology off cocaine addiction. When a person takes cocaine, the drug is picked up by the N. Accumbens and the person feels "high", powerful, with thinking accelerated (although superficial) and ready to act. How does this end up in pathology? The cocaine substitutes for dopamine and the dopamine becomes depleted. The lowered dopamine level is associated with the inhibition of thinking, a painful mood, and inhibited action. The amygdala, as well as other sub-cortical centers send their activating (or de-activating) inputs to the basal ganglia via the N. Accumbens (at least, partially). Thus the cocaine addict, in the withdrawal phase, cannot renew his dopamine charge; consequently, his basal ganglia cannot be activated in a normal way. Re-entry also means that the cortical and sub-cortical mechanisms (the amygdala as well as the central gray matter, which give connections to emotional and physical pain perception) will receive messages from the Nucleus Accumbens – Basal Ganglia complex. The unfortunate outcome is that the addict is in for a long period of painful withdrawal before his dopamine metabolism can be restored. (One cocaine dose can throw off the Nucleus Accumbens for months.)

The point is that these sub-cortical mechanisms, which can create vicious circles among themselves, will then send up messages to the cortex to make us conscious, in this case, painfully so, of what is happening below the surface of cortex.

The Frontal Lobe

The research of Antonio Damasio and Edmund Rolls has given us basic insights regarding the neural pathways and functions of the frontal lobe.

The frontal lobes occupy one-third of the cortex. Their basic function is to integrate diverse cortical and sub-cortical structures. If we can imagine two major inputs: one from the external world, the other from the internal viscera. The frontal lobes **integrate** these external and internal sources of input. A simplified schema is as follows:

Stimuli from the **environment** are transmitted by the ascending reticular systems (ARS) to the thalamus. The thalamus, a relay station, then sends the neural patterns upwards to the posterior cortex. From there the messages are sent forward to the temporal lobe (to become connected to the memory of previous situations), to the parietal lobe (for generalization, abstraction and mathematical analysis), and to the lateral part of the frontal lobes (to register the environment).

Stimuli from the **internal viscera** enter the brain in a totally different way: by means of the vagus nerve to the solitary nucleus of the brain stem. From there "climbing neurons" (Nauta) reach various levels of the brain: hypothalamus, amygdala and the inner part of the frontal lobes, called the orbitofrontal lobe.

Thus the frontal lobes brings together inner and outer reality in order to give us experiences of situations, or **"episodes,"** that are emotionally meaningful. This is its integrative function.

Frontal Lobe Outputs

The frontal lobes influence **performance.** Based on the integrated episodes, what do we want to do? The frontal lobes create decision-making. The decision is then sent to the motor areas in two ways: One is direct: To the cortical pre-motor and supplementary motor areas. The other is indirect, but of great importance: To the basal ganglia, which organizes action sequences and routines. (From the basal ganglia, complex motor patterns are then sent to the thalamus and from there to the motor cortex for final execution of the action.)

Other significant outputs of the frontal lobe: Messages from the integrated episodes are sent to other cortical areas. Messages to the parietal lobe reinforce patterns of thought and understanding. Messages to the temporal lobe reinforce memories. And messages to the posterior cortex that first registered the environmental stimuli and integrated them into multi-modal perceptions become reinforced. This is called "priming," and favors attention to the perception of emotionally-relevant environmental cues: facial expression, movement of an object, voice sounds, etc.

Since these messages run through different cortical areas we will call the "horizontal output" of the frontal lobes.

The frontal lobes also send **descending messages** to lower parts of the brain: to the amygdala (emotional processes), hypothalamus (hormonal output, sympathetic-parasympathetic balance) and solitary nucleus and dorsal motor nucleus of the vagus (visceral regulation).

Thus the very large frontal lobes receive multiple inputs, create an enormous integration of inner world and outer world perceptions, connect these episodes to thoughts and memories, and conclude with outputs for action, emotional response and internal visceral regulation.

Antonio Damasio makes a very interesting point: The multiple inputs and outputs of the frontal lobes replicate the inputs and outputs of the sub-cortical amygdala. Therefore, the frontal lobes could represent an advanced form of the amygdala. In other words biological evolution involving the brain created, by means of the frontal lobes, a more advanced and complex structure that becomes superimposed on the more primitive amygdala. Both function together. Therefore, as so often happens in the brain, neural patterns may be repeated at different levels. This increases the brain's capacity for fine complex regulation and control.

The Cingulate Cortex

Recent research has brought to light the important functioning of the cingulate cortex. This cortical area seems to be an intermediary region (located close to the corpus collosum) between the amygdala and orbito-frontal lobe. The cingulate gyrus is composed of a number of sub-regions. While the **posterior** region, like the **lateral** aspect of the frontal lobes, is more concerned with environmental perception, the **anterior** region, like the orbitofrontal lobe and medial frontal lobe, is involved with emotions. One of the most interesting functions of the anterior cingulate cortex (ACC) is to highlight "novelty" as well as "dissonance" between expectations and what really occurs. In fact, the conscious sense, "something is wrong," emerges from the cingulate cortex.

One specific consequence: Obsessive-compulsive patterns are based on automatic thought and action patterns that stem from a basic feeling, "There is something wrong." The compulsive action gives partial relief to the feeling of discomfort. But the discomfort is not eliminated and will return the moment the action is terminated. (The cinglate cortex, like its companion orbitofrontal cortex, sends messages for initiating an action to the basal ganglia.)

The cingulate cortex receives inputs from various cortical association areas, the amygdala, the hypothalamus and brainstem nuclei that give visceral feedback. The outputs of the cingulated gyrus are also multiple: to cortical areas, to the Nucleus Accumbens and basal ganglia, to lower subcortical regions such as the hypothalamus, brainstem centers of neuromodulator secretion (tegmentum, locus coeruleus), and the brainstem nuclei of visceral regulation.

What is fascinating is that this reproduces input and output schemes that characterize the orbitofrontal lobe and amygdala. Therefore the brain is **repeating** circuits and functions. We can hypothesize several consequences: Fine tuning, complexity, reliability and stability. The brain must not make errors. Perhaps this repeating and overlapping of functions, especially when elusive emotions are involved, gives a guarantee that the brain functions will not slip into error. Too much is at stake: the survival of the organism.

Conclusion

I am sure that other clinicians, working hand in hand with neurophysiologists, can propose yet other sub-cortical/cortical mechanisms to account for psychological problems and their treatment. Whatever the mechanism (and we can expect, as in all of our examples, many more will be discovered), it is the sub-cortical process that **drives** the conscious cortical experience. Imagine a wave in the ocean. Our mental life is like the foam (cortical consciousness) that is on the top of a wave, very bubbly, very lively, but not autonomous. Rather, the lively foam is generated by the powerful movement of the water spiralling below, just as cortical processes, including consciousness, ride upon the sub-cortical dynamic.

Bibliography

Bush, George e al, **"Cognitive and Emotional Influence in anterior cingolate Contex"**, Elselvier Science Ltd, 2000, pp. 215-217.

Damasio, Antonio, "The Frontal Lobes" (Ch. 2) in Victor, Maurice & Ropper, Allan H., **Principles of Neurology**, 7th Edition, McGraw-Hill, 2001.

Edelman, Gerald M., **The Remembered Present,** A Biological Theory of Consciousness, BasicBooks, 1989.

Edelman, Gerard M., **Wider Than The Sky**, Yale University Press, 2004.

LeDoux, Joseph, **The Emotional Brain**, Phoenix, 2003.

Ochsner, Kevin and Barrett, Lisa, "A Multiprocess Perspective on the Neuroscience of Emotion", (Ch.2) in Mayne, Tracy J. & Bonanno, George A., **Emotions. Current Issues and Future Directions**, New York, The Guilford Press, 2001.

Rolls, Edmund T., **The Brain and The Emotion**, Oxford University Press, 1999.