Bridging Emotion and Cognition
A Role for the Prefrontal Cortex in Polygraph Testing

Mark Handler, George Deitchman, Thomas Kuczek, Scott Hoffman & Raymond Nelson

Introduction

Opponents and proponents of psychophysiological detection of deception (PDD) have both highlighted and acknowledged a lack of generalized agreement for the cause of reactions measured during testing. Efforts have been made towards elucidating these causes in order to provide a better understanding of the basic constructs underlying PDD testing.

Handler and Honts (2008) proposed that the understanding of the psycho-physiology of deception detection may be usefully addressed through the framework of the traditional concepts of the orienting response (OR) and defense response (DR), based on the signal value content or salience of the test question stimuli. They discussed how the physiological responses reported during OR and DR are consistent with those responses measured and evaluated during PDD testing. Khan, Nelson and Handler (2009) and Handler, Shaw and Gougler (2010) extended the discussion of ORs and DRs and suggested that inextricable links between cognition and emotion indicate that cognitive appraisal plays a more significant role than previously recognized in the triggering of emotional states and concomitant physiological reactions. And while the hypotheses of "emotion in cognition" and "cognition in emotion" seem to have face validity, the discussion was presented without empirical support. What

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was lacking was a higher-level theory that describes the purely psychological constructs that would define the processes within which an individual attaches greater salience to some test stimuli and how that salience was then measured and evaluated. This paper proposes that the prefrontal cortex (PFC) is at least partly, if not considerably, involved in integrating these psychophysiological processes of assigning value and modulating measurable responses.

The main goal of this work is to provide the existing evidence in support of the hypothesis that the PFC is involved in the integration of cognition and emotion in the PDD testing milieu using evidence gleaned from current neurophysiological and neuropsychological research on the PFC. Because the PFC is reciprocally connected to many areas of the brain including: all cortical regions, sensory related thalamus, memory related nuclei and sub-cortical structures that contribute to autonomic arousal, it is in a unique position to bridge the related functions of cognition and emotion. Inputs and outputs to the PFC play a significant role in executive function, planning and decision making in goal-oriented attention and behavior. Goal oriented attention and behavior are thought to be an indication of the salience of sensory information and central to differential responses to PDD test stimuli.

The PFC plays a major role in sustained attention to, and inhibition of, signal value stimuli necessary for the occurrence of an OR, a DR, or an emotional response (Sokolov, Spinks, Naatanen & Lyytinen, 2002). PFC outputs to the hypothalamus, as well as the autonomic and brain stem nuclei that result in responses measured during PDD testing will be reviewed. Included is a brief overview of the neurotransmitters that have been found to facilitate neural transmission to and from the PFC and how they are thought to be involved in general arousal as well as specific goal related behavior. Neurophysiological evidence in support of how the PFC is involved in the temporal control of complex goal related behaviors is offered. Also discussed is the neuropsychological evidence for area specialization based on lesion and trauma studies. Finally, the findings gleaned from neuroimaging studies in support of the PFC involvement in executive functions will be reviewed. The totality of this evidence provides support for the hypothesis that emotion and cognition are inextricably involved in the phenomenology of reactions measured during PDD testing, and the PFC is intimately involved in both.

Emotion and Cognition - An Overview

Emotional reactions occur when an organism is in an emotional state, and are characterized by the presence of four major components: cognitive, biological, behavioral and affective (Barlow, 2002; Bradley & Lang, 2000; Damasio, 1999 & 2000; Lazarus, 1991; Power & Dalgleish, 2008; Scherer, 2000). The cognitive component accounts for the conscious or unconscious perception and appraisal of a stimulus in terms of emotional significance or meaning to the subject. A number of the aspects of executive functions can be subsumed under the category of cognition, including attention, working memory, timing of behavior, and monitoring results.

The biological component of emotional reactions includes the bodily effects resulting from activation of the autonomic and brain stem nuclei, some of which result in changes in evaluated measurements in PDD testing (cardiovascular changes, electrodermal responses, and somatic quiescence). Emotional responses also include a behavioral component that results in an impetus to engage in action or behavior, and is often the most useful point of observation when seeking to understand a person's motivation and goals. Finally, there is the affective or feeling component, which includes the subjective perception of the bodily expressions and concomitants of the emotional response. Feelings result from the mapping of body states and body state changes occurring during emotional responses (Damasio, 1999).

Emotional responses are not “one and done” phenomena, as their normal progressions include reappraisal and updating of the contextual situation, allowing for adjustment of any of the contributing components. Emotional responses begin with the perception of an “emotionally competent stimulus” (Damasio, 2003). Perception is essentially representations of the world being processed as they impinge upon receptors within the nervous system. Perception may result in additional cognitive tasks that include aspects of attention (selective attention and inhibition) or memory (working or long term) and it may lead to behavioral acts. Fuster (2008) refers to this as the "perception-action cycle." The concept of this updating "reappraisal" component will be developed, modifying Fuster's term to the "perception-action-appraisal cycle." This appraisal and updating is the likely capstone of PFC contribution to cognitive reactions during a PDD test and interview process and will be discussed further later in the paper.

Overview of PFC

The prefrontal cortex (PFC) is a term commonly used to refer to the portion of the brain located at the frontal pole. Hodological (i.e., fiber pathway) approaches have been used to identify areas of the frontal lobes considered PFC, as these methods highlight the interconnected and integrative nature and function of PFC. In humans, the PFC constitutes about one third of the entire cortex and roughly includes the frontal lobe, minus the motor and pre-motor cortices. While the PFC has reciprocal connections with many cortical and sub-cortical areas, the PFC-medial dorsal thalamic connections have been documented as being universal throughout mammalian brain anatomy.

The thalamus "anteroom" is known to have multiple functions and it is generally believed to transform inputs that are processed into signals that can be selectively passed on and read by the cerebral cortex according to the signal value of the stimulus. In humans, all sensory input, except olfactory, is initially processed through the thalamus. The thalamus is divided into the lateral, anterior, and medial portions. It is the medial thalamus that is known to subserve visceral and emotional systems. Brain regions involved in components of emotion such as the anterior hypothalamus, reticular formation, substantia nigra, septal nuclei, and especially the amygdala, all include neuronal projections to the medial-dorsal (MD) nucleus of the thalamus. MD, in turn, has reciprocal projections to the PFC,

Figure 1. A diagram of areas of cortex with reciprocal connections with the MD nuclei.

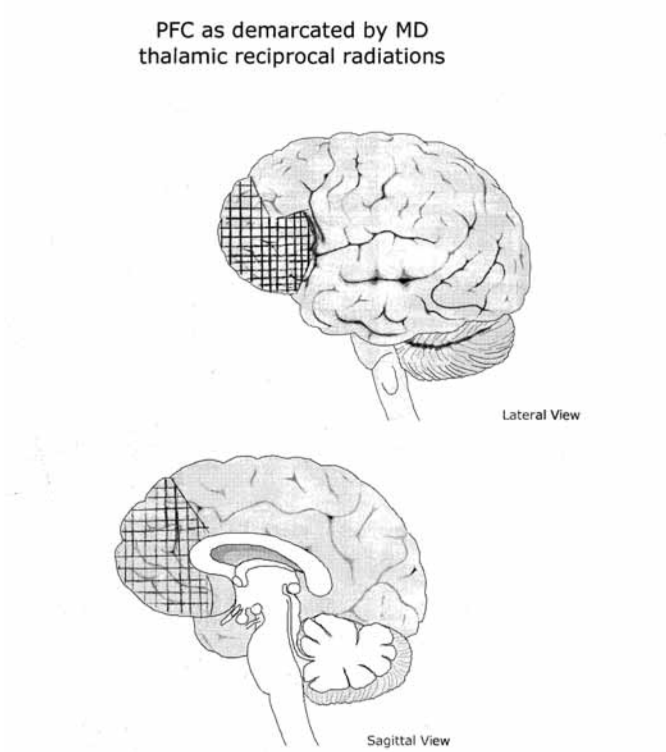
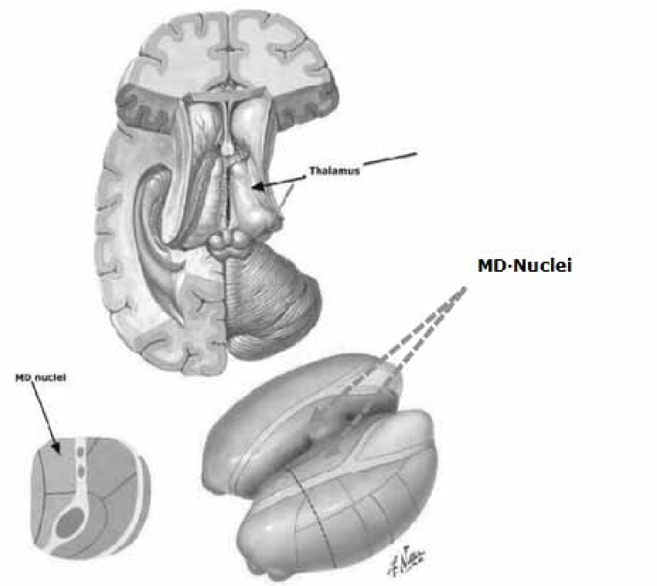


Figure 2. A diagram of the thalamus, showing the MD nuclei.



allowing each to inform and update one another. One of the putative purposes of this communication between the MD nucleus and the PFC is for integration of emotion and memory (Fuster, 2008; Nolte, 2009) that contributes to learning.

Afferent connections to PFC are not limited to the thalamus. The PFC also receives direct inputs from the amygdala, hypothalamus, pons and brain stem tegmentum, as well as via serotonergic, dopaminergic and cholinergic brainstem nuclei pathways. Thus the PFC receives inputs related to autonomic arousal, emotional values of stimuli and general levels of cortical arousal. The PFC has reciprocal communication with the hippocampus, which has been suggested to play a role in memory, learning and motor programming (Eichenbaum, 2002). Finally, the PFC is extensively interconnected with other cortical regions and cortico-cortical fibers have been found to originate in primary areas associated with hearing, vision, touch, smell and taste (Fuster, 2008; Nolte, 2009).

Efferent[1] connections from PFC are reciprocal with all structures with one notable exception, the basal ganglia:[2] The PFC has strong efferent premotor and supplementary motor connections with striatum structures (caudate and putamen[3]) but they do not seem to have afferent connections to the PFC. The PFC has strong reciprocal efferent influence on the MD thalamus, as well as the amygdala, hippocampus (via entorhinal cortex), and

[1] Efferent neurons are commonly understood as outgoing, whereas afferent neurons are incoming.

[2] Basal ganglia are a group of neurons that pay a role in motor activity, cognition, emotions, and learning and related to conscious directed activity.

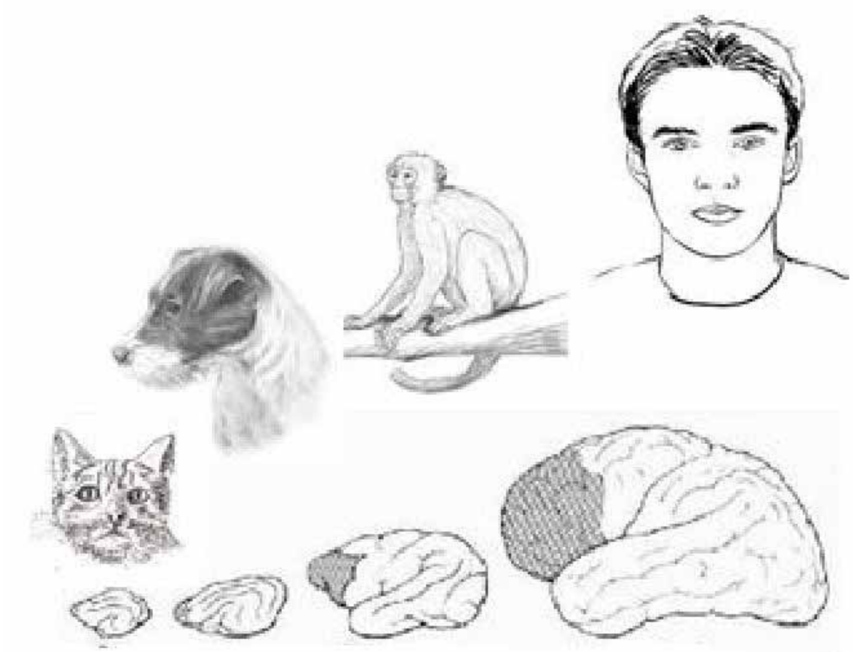
[3] Current evidence suggests that the dorsal striatum (caudate and putamen) contributes to decision-making, especially to action selection and initiation, via the integration of sensorimotor, cognitive, and motivational/emotional information within specific corticostriatal circuits. Studies in humans corroborate animal research suggesting that the dorsal striatum is an integral part of a circuit involved in decision-making. Accumulating evidence, primarily from neuroimaging but also neuropsychological investigations, has implicated the dorsal striatum in different aspects of motivational and learning processes that support goal-directed action.

hypothalamus (Fuster, 2008). The net effect of these projections is that the PFC can influence behavior (including language), reasoning, memory, and autonomic physiological responses.

PFC myelination,[4] and resulting interconnections, develops later in human life. Most adult PFCs are not completely myelinated until the person is in his or her 20s, which seems to coincide with cognitive functions of maturation. Neuroimaging studies suggest that until the PFC is fully myelinated, higher cognitive functions such as planning, decision making, intelligence and reasoning are not fully operational (Benes, 2001; Fuster, 2008).

As animals move higher up the evolutionary hierarchy, the size and function of the PFC increases commensurately. The increase in PFC size (and shape) is not uniform, but is proportional to the areas most involved in increased cognitive influence over control of behavior. The lateral convexities[5] are thought to have the greatest influence over purposeful behavior and cognitive control and they increase in size disproportionally to other aspects of the PFC. The lateral aspects of the PFC are known to be those most involved in temporal coordination of complex behavior. The ability to control the timing of behavior allows one to coordinate goal directed thoughts, plans and ideas into actions. Without temporal coordination of goal directed behavior, one would be relegated to reactionary actions, incapable of future planning and decision making.

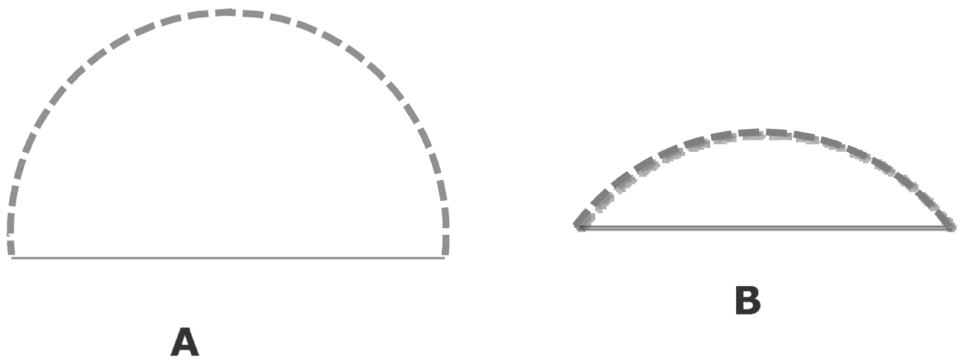
Figure 3. Approximate portions of cortex considered to be PFC in the cat, dog, Rhesus monkey and man for comparison.



[4] Myelin is an insulation layer, usually around the axon of a neuron, that serves to organize, direct and speed the transmission of neural impulses.

[5] Lateral convexities are large curved areas on the side two sides of the brain.

Figure 4. A demonstration of how evolutionary expansion of the later aspects of the PFC can affect surface area. As brains progress evolutionarily, there is an increase in the lateral convexity (dashed line area). The brain with shape A would have a greater surface area than that of one with shape B.



Communication between neurons is accomplished and modulated via neurotransmitters and we will provide an overview of the primary neurotransmitters that affect communication to and from the PFC. Drugs of abuse are known to affect receptors for most of the many chemicals involved in these processes and can thus have an effect on manifestation of psychophysiological responses during cognition and emotional processing. The neurotransmitters involved in PFC communication primarily include: Gamma-Aminobutyric acid (GABA), glutamate, norepinephrine, serotonin, dopamine and acetylcholine.

GABA, an inhibitory transmitter, is abundantly found in the PFC and the brain and exerts its inhibitory influence primarily via interneurons. GABA inhibitory action is thought to be one of the mechanisms of increasing the saliency of excitatory neuronal connections by quieting or inhibiting irrelevant or competing stimuli in working memory (Fuster, 2008).

Glutamate is the primary excitatory neurotransmitter used within the PFC for communication. Glutamate is also the main excitatory transmitter used for communication between the PFC and caudate/ putamen,[6] hypothalamus, amygdala, MD nucleus and hippocampus. Glutamate does not cross the blood brain barrier established by astrocyte glial cells. Reciprocal connections between the PFC and the hippocampus involve NMDA receptors.[7] These are found in large numbers in the PFC and the hippocampus, and are sometimes referred to as "coincidence" receptors because they require the postganglionic cell to be depolarized when glutamate is present at the receptor. This two-step requirement results in strengthened connections between cells and is thought to be involved in neural plasticity, learning and associative memory (Fuster, 2008; Nolte, 2009).

The PFC receives extensive innervation from sub-cortical structures that are a part of the acetylcholine (ACh) system. These sub-cortical structures are able to exert an excitatory influence over the PFC that in turn is able to excite or inhibit other brain areas such as posterior sensory and association cortex. In addition to glutamate GABA, and ACh, three monoamines heavily innervate the PFC. Norepinephrine, serotonin, and dopamine originating from traditional brain stem regions bypass the thalamus and innervate the PFC.

[6] Thought to play a role in motor planning tasks such as speaking or moving.

[7] NMDA receptors are a specific type of glutamate receptor that is selectively blocked by the N-methyl-D-aspartate agonist, and are thought to play a role in learning and memory.

Norepinephrine projections originating in the locus coeruleus in the medulla enter at the frontal pole of the brain and then flow caudally, innervating much of the entire cortex. These norepinephrine projecting cells fire according to arousal state and in response to highly salient stimuli. The norepinephrine system is thought to provide a general arousal effect throughout the entire cortex, including the PFC. Moderate increases in norepinephrine increase cognition, attention, and memory, while large increases have a deleterious effect (Fuster, 2008). Stress is known to increase norepinephrine levels and stress experiments have been used to measure effects on cognitive capabilities. Moderate levels of stress enhance performance, while high levels can produce detrimental effects. There appears to be a relationship between stress/norepinephrine level and the effect on cognition that follows an inverted-U pattern (Fuster, 2008; Yerkes & Dodson, 1908).

Serotonin is most heavily concentrated in somatosensory brain areas though it does innervate areas of the PFC, including the orbital cortex.[8] Serotonin has been found to have an important inhibitory role, by exciting GABA cells to cause them to inhibit other cells. This inhibition may help modulate behavior and emotion and is probably accomplished via effects on other brain regions with which the PFC reciprocally communicates.

Dopaminergic projections to the PFC are extensive. One well-established dopaminergic pathway is the mesocortical projection from the ventral tegmental midbrain to the nucleus accumbens, amygdala and septal region. This pathway is thought to be heavily involved in goal directed movement, cognition, fear, anxiety, stress, reward prediction and motivation. In the PFC, many dopaminergic “predictor” cells not only signal when a reward is imminent, but also signal when a stimulus associated with the reward is presented.

Neuropsychological and Neurophysiological Findings on the PFC

The PFC is both an association cortex and a cortex devoted to action. The research on the PFC to date supports it being considered an integrative cortex of both sensory and motor operations. The PFC receives sensory cortex inputs for all modalities via thalamic and cortical pathways. Many of these cells react most strongly to stimuli that are behaviorally significant or otherwise high in signal value (Fuster, 1973; Yamatani et al., 1990). It is suspected that diencephalic structures (especially the hypothalamus) related to emotion, form associations based on prior experience or prior exposure. The PFC is well known to be involved in selective attention to sensory stimuli and participates in the inhibition of extraneous stimuli to maintain attention.

The PFC is known to modulate discharge of motor related cells in the caudate as well as regulating inhibitory control on the hypothalamus. Certain cells of the PFC become active in preparation for movement and this anticipatory priming prepares the organism for the event, providing an advantage for faster responses in goal directed behavior. The PFC contributes to actions (skeletal, muscular, emotional, and visceral) through cooperation with other cortical and sub-cortical regions. It is most involved with complex, goal related actions requiring planning and cognitive intervention. The more complex and idiosyncratic the action sequence, the more cognitively involved the action plan must be to coordinate the activity.

The PFC has extensive output to brainstem, autonomic and hypothalamic structures that modulate emotional responses and reactions. Orbital and medial aspects of the PFC are more strongly associated with direct innervation of these structures, while the lateral PFC innervates as a result of executive functioning. Medial,

[8] Located at the front and sides frontal cortex, the orbital cortex is thought to play a role in moral reasoning and the anticipation of emotional consequences for planned behavior.

orbital and lateral PFC functions are inextricable and influence hypothalamic and brainstem outputs via an integrative process. Stimulation of these areas is known to increase blood pressure, change heart rate, result in electrodermal responses and inhibit muscle movement (Boucsein, 2012; Hess, 1969; Le Bar, 2009; Le Doux, 1993, 1996, 2002). These are accomplished via efferent connections from the PFC to amygdala, hypothalamus and autonomic brainstem nuclei (Le Doux, 1993, 1996, 2002). The PFC output to the hypothalamus and amygdala is undoubtedly involved in emotional behaviors and responses and include those that are measured and evaluated during PDD testing. As can be appreciated by these interrelationships, there is always cognition in emotion, and emotion in cognition. The cognitive aspects of planning, decision making, and appraisals are influenced by emotion and without emotional feedback rational behavior suffers (Damasio, 1994; Damasio, 1999; Fuster, 2008; Le Doux, 1993, 1996, 2002).

While it is not possible to ascribe task specificity to individual PFC regions, certain areas do seem to more heavily influence components of executive function, as evidenced by studies of lesions from disease, trauma, or frontal psychosurgery (Damasio, 1994; Damasio, 2000; Fuster, 2008; Nolte, 2009). Large prefrontal lesions, especially involving the medial and lateral cortex, often result in apathetic behavior and decreased motility. Symptoms of a lateral syndrome include attention deficits, movement and decision apathy, depression, poor planning, and reduction of working memory. Working memory deficits manifest themselves in a number of ways but are often appreciated in a reduced ability to effectively plan and make decisions, in addition to deficiencies in recalling recently acquired information. Decision making and planning require holding in mind, internal representations while considering outcome possibilities. Without a properly functioning working memory, subjects are relegated to rigid behavioral programs, (i.e. living for the moment.)

Orbital cortex syndromes, on the other hand, result in disinhibition, perseveration, reduced moral constraint, hypermotility, distractibility, impulsivity, reduced ability to empathize and reduced bodily sensations of emotional responses (Damasio, 1999; Damasio, 2000; Fuster, 2008). Behavioral consequences of disorders of orbital cortex lead to poor social decision making, increased risk taking, inappropriate emotional responses, and poor social restraint. Damage to anterior cingulate or medial aspects of PFC can result in loss of drive, lack of initiative and general apathy. In summary, damage to each of the major PFC regions can be expected to result in generally accepted and identifiable clusters of symptomology.

PFC Functions

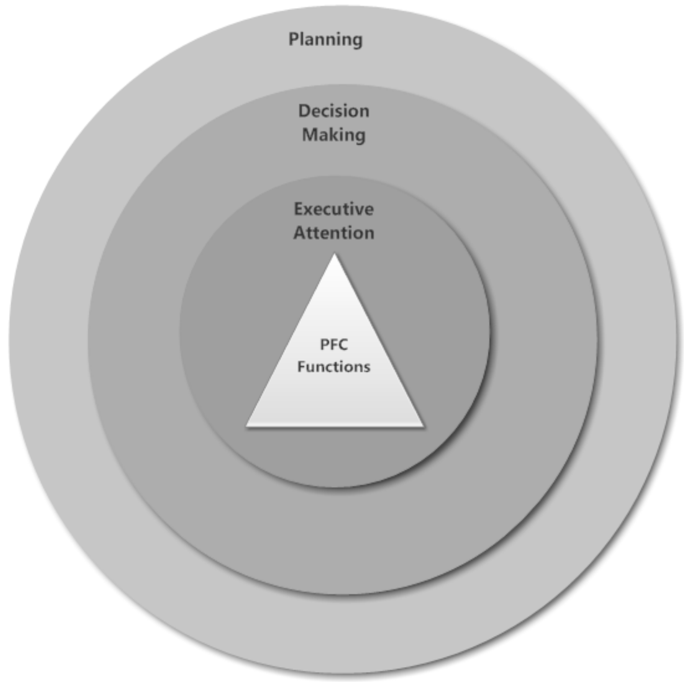
Primary functions attributed to the PFC include planning, decision making and "executive attention" (Fuster, 2008).

Executive attention is that function of the PFC related to working memory, sensory and motor priming and interference inhibition. Working memory is the process of actively holding in mind an internal representation when it is no longer present in the environment (Postle, 2007; 2009). This representation may be sensory, perceptual or motor related and it can be of a past or future goal. Working memory is a "state" of a memory that is being attended to at the time and integrates PFC with other cortical areas where aspects related to the representations are stored. Working memory of a cognitive or behavioral goal is mediated through a cognitive network of the particular memory, sometimes referred to as "executive memory". Executive memory traces include the sensory input and motor output aspects of the prior event, and extend into those cortical areas from which they came and where they went.

Sensory or motor priming is sometimes referred to as a "preparatory set" and involves the making ready of neural structures to act. Evolution favors a system that can prime or prepare for activation, and aspects of the PFC are capable of lowering thresholds of activation through priming. The end result is that neural structures are capable to influencing behavior more quickly by being placed "on notice."

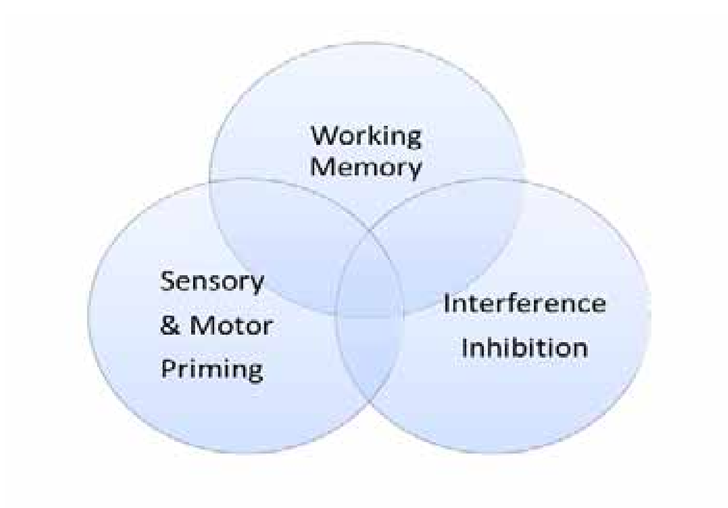
The ability of an organism to inhibit cognitive, emotional and behavioral inputs is

Figure 5. PFC functions include: planning, decision making and executive attention.



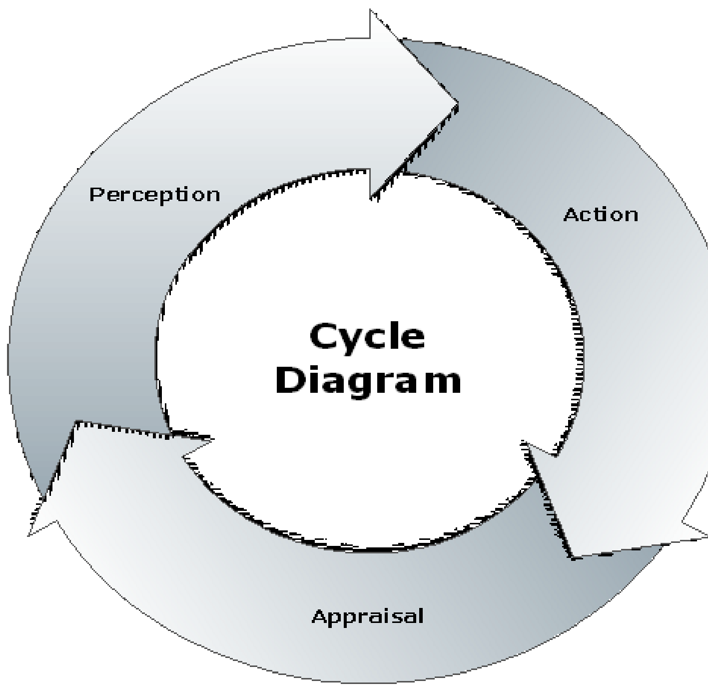
of critical importance to goal directed and intelligent behavior. Interference inhibition falls primarily within the purview of the orbital and medial aspects of the PFC. Without an ability to filter out unnecessary and less important interferences, decision making and planning abilities would be markedly diminished. The inhibitory influences of the orbital and medial PFC on the lateral PFC functions highlight the symbiotic and integrated nature of cognitive networks of the PFC.

Figure 6. Components contributing to executive attention.



While the PFC is considered to be involved in the cognitive integration and coordination of such behavior, it is not the only region involved in goal seeking. Goal directed behavior best results from assessments and updating of sensory information provided from within and outside of the organism. The PFC is involved in integrating the incoming information and formulating plans of actions by other neural structures. Those plans may be based on memories of similar previous situations or through feedback from actions taken. This continual updating of actions is at the heart of the perception-action-appraisal cycle. Through feedback and updating, the PFC is able to modify, adjust or continue the current course of action in pursuit of the goal at hand.

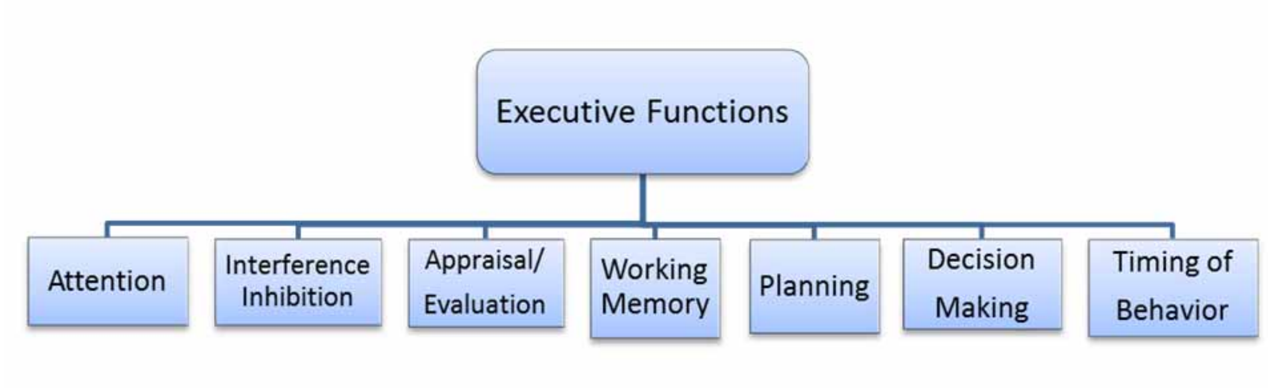
Figure 7. The Perception-Action-Appraisal cycle.



Executive Functions

Executive function is a term often attributed to the PFC, sometimes without further explanation or descriptions. Aspects of executive function include: attention, interference inhibition, appraisals and evaluations, working memory, planning, decision making, temporal integration of behavior, monitoring and feedback (Fuster, 2008). These executive activities are so closely aligned with the functions of the PFC that the terms “executive” and “PFC function” can be easily substituted for each other. The PFC is heavily involved in coordinating purposeful action toward the achievement of goals. All aspects of this require the timely organization of behavior, including when to act, when to inhibit actions and in the reassessment of the results. This is not to state that the PFC is solely responsible for executive function, as the entire cortical and many sub-cortical areas are involved in accomplishing goal directed tasks. The perception-action-appraisal cycle is a model which helps illustrate how the PFC is centrally placed to receive perceptual information, access memory, formulate plans and coordinate action of goal directed behavior.

Figure 8. Cognitive functions subsumed under the umbrella of executive functions.



Neuroimaging Study Findings

Neuroimaging studies provide support for PFC involvement in executive function tasks. Blood oxygen level dependent (BOLD) fMRI has shown PFC activation correlates directly with attention (Roland, 1981; 1982). Wagner, Reading and Jonides, (2004) concluded in their meta-analysis that sustained attention results in activation of both the PFC and the same cortical areas activated by the task. Neuroimaging studies provide evidence for active cognitive control processes involved in sustained attention to stimuli in the PFC (Owen & Hampshire, 2009). Those authors concluded that the mid-ventrolateral PFC region plays an attention role in specific, intended and willful behaviors and thoughts.

The bulk of BOLD neuroimaging studies that include the PFC investigated working memory. Recall that working memory is the holding in mind of an internal representation over time. Its success requires sustained attention on the salient stimuli representation and an inhibition of attention to competing or extraneous stimuli. Studies involving the rehearsing and refreshing of stimuli being held in mind support PFC activation during these working memory tasks (Johnson & Johnson, 2009).

Imaging studies have found an increase in PFC activation with an increase in target complexity. The more difficult the task of holding in mind the target, the greater the PFC response. The left PFC seems to be more highly involved in language related targets, while the right has greater influence or activation during spatial tasks. During working memory activity it appears as though there is continual intercommunication between the PFC and the cortical areas responsible for the perception. This imaging finding supports neuropsychological evidence for the maintenance of long term memory (Eichenbaum, 2002). During working memory tasks, priming by the PFC has been observed in sensory and motor cortices, supporting the concept that working memory activities can include a preparation for action. Neuroimaging studies have provided evidence for the working memory tasks of refreshing and rehearsing within the PFC (Johnson & Johnson, 2009).

Consistent with neuropsychological prediction, PFC activation was greater in orbital, medial and anterior PFC regions during emotional planning and decision making. When subjects were imaged during non-emotional decision making and planning, the lateral aspects of PFC were activated to a greater degree. Risk and reward involved tasks have constantly shown activation in orbital and medial PFC (Blair et al., 2006; Daw et al., 2006).

Language

Spoken language is one of the most complex behaviors in which humans engage. No other behavior would seem more germane to the PDD setting than language. During PDD testing, it is feasible that test subjects will involve many of the aspects of executive functions; emotion and cognition that have been discussed. The greater the cognitive complexity of the language task, the greater the expected arousal. For this reason, PDD test questions would ideally be of approximately equivalent length and verbal complexity.

If the test subject is not truthful, the cognitive complexity of the task would increase due to the stimulus itself and not the length or complexity of the question language. One can assume that most subjects with something to conceal will be sufficiently motivated to "pass" the PDD test so that they will have some plan for lying. Success would require a deceptive subject to create a script, a task that most subjects are probably capable of. The script must be sufficiently detailed to appease the interviewer while not alerting them to the presence of incorrect information or missing details.

The subject must anticipate questions and provide plausible answers. The subject's version must withstand probes, by the interviewer, which can be difficult. The subject may have to think quickly, improvise, avoid contradictions, remember what they said and do so convincingly. Lying subjects are less likely to take their credibility for granted so they are likely to engage in behavior control in an attempt to ensure a credible presentation. Truthful subjects will also attempt to portray a credible presentation, but the cognitive demands to accomplish this can be assumed to be lower than that of deceptive subjects who must also attend to the difference between deceptive and factual information. Lying subjects will likely be evaluating the interviewer's response for feedback, and can be expected to make different use of that feedback in response to both behavioral presentation and factual information, whereas truthful subjects may have reduced cognitive demands pertaining to managing and differentiating factual information from deception (Vrij, 2008). All of these tasks, and more, can result in cognitive loads becoming extreme and testing the limits of working memory, planning and decision making. Recent fMRI studies have shown pathological liars have increased PFC white matter compared to normal individuals or even those diagnosed with antisocial behavior and no history of pathological lying. This finding suggests either increased use by lying causes the white matter volume to grow larger or that the increased glial density predisposes the subject to pathological lying (Yang, Raine, Lencz, et al., 2005; Yang, Raine, Narr et al., (2007).

Summary

In building a case for the physiological underpinnings of PDD responses in brain function, the PFC clearly deserves the primary attention of the researcher. The role of the PFC in higher-order cognition and behavior is demonstrated by its exponential increase in proportional physical mass and importance when plotted against the more linear function of the evolutionary hierarchy. This is well illustrated by noting that while humans and rhesus monkeys share approximately 93% of their genetic sequence, the human PFC is orders of magnitude physically larger and more complex than that of their lower-order evolutionary relative. This is not surprising, given the cognitive superiority of humans in such areas as abstract thinking, linguistics, introspection and meta-cognition.[9] The complexity of cognition enabled by the PFC is also apparent in the importance of emotion in human consciousness, which both results from and serves as a precipitator of behavior. In addition to the range and depth of cognition granted by the PFC, it also permits a strategic system of continuing appraisal of the environment to maximize the utility of behavior.

Structurally, the PFC has strong hodological linkages to other brain structures of interest in the PDD environment, including the amygdala (emotion), the hippocampus (memory and learning), the brain stem (autonomic arousal), and the sensorimotor areas of the cortex (affect or feeling). Within its own structure, the PFC exhibits significant structural specificity in regard to distinct functions of sensory input and behavior.

[9] While the term cognition refers, in general terms to the process of thinking, meta-cognition refers to the process of thinking about one's thinking. Meta-cognition differs from introspection which deals more with a broader contemplation of personal experience.

Functionally, the executive role of the PFC represents some of the highest order processes of which the human brain is capable, including the association of stimuli into meaningful representations of the environment, selective injunctive action against irrelevant or meaningless stimuli, and the formulation and implementation of complex behavioral responses that effectively serve the survival needs of the subject. The level of response complexity permitted by the executive functioning of the PFC is truly remarkable at all levels, ranging from anticipatory priming of behavioral responses to formulating immediate linguistic responses to verbal stimuli.

Of particular interest to PDD researchers are latent indicators of autonomic arousal that are produced by PFC in parallel with manifest linguistic deception. Indeed, these indicators of autonomic arousal are correlated with, and hypothesized to constitute, an unintended side effect of the discordance between the record of events a PDD examinee remembers to be true (i.e., the "ground truth") and a purposeful, contrary linguistic behavior (i.e., lying to a relevant question). This lying behavior is intended to protect the subject from perceived threat to goal achievement (e.g. discovery of culpability regarding the relevant issue being investigated or not being hired for a public safety position).

All mammals would understandably experience autonomic arousal in the presence of threatening stimuli, but the concept of "telling a lie" would logically only apply to the most highly developed mammals, humans, who have the capacity for complex language, social adeptness, calculations of risk and reward, and a conscious motivation for the preservation of the self and its interests into a future tense that is desired but has not yet occurred. It could be argued that some lower-order animals engage in "deception" by concealing their position, or through imitating the appearance or sound of another species to gain an environmental advantage. These behaviors among lower-order animals are difficult to attribute to conscious control. Indeed it would seem that the application of the concept of "intentional deception" to lower-order animals may be an anthropomorphic exercise because it presumes that the behavior is voluntary and selective. Research has shown, however, that deception animals perform is directly proportional to neocortical volume (Byrne & Corp, 2004). Deception among humans is infinitely more complex, capable of accomplishing goals via misrepresentation, omission, misdirection and as illustrated by the famous case of a former chief executive, semantic trickery in the form of questioning "what the meaning of 'is' is" (Starr, 1998.) Of note is the crucial importance of situational and temporal specificity in human linguistic deception, such that an identical statement can transition between being demonstrably true or demonstrably false based on differences in context or the passage of events. The statement of another chief executive that "the British government has learned that Saddam Hussein recently sought significant quantities of uranium from Africa" (Bush, 2003) would have been a lie if the absence of evidence were known. However, it would simply amount to inaccurate information if the absence were unknown, and would have been true if evidence were identified. In the PDD setting, which does not attempt to measure lies per se, the examinee's physiological response to verbal test stimuli can be understood most effectively not as a function of the examiners logical or linguistic precision but as a combination of cognitive and emotional responses to the verbal stimuli that describes the examinee's past behavior.

The PFC should undoubtedly be the focus of future investigations into the biological underpinnings of recorded responses to PDD stimuli. It demonstrably has strong pathways with all other structures relevant to complex behavior and, thusly, behavior associated with purposeful linguistic deception regarding past behavior. It has been demonstrated that the PFC is intimately involved in the performance of executive functions of special importance that cannot be structurally attributed elsewhere. It functions as an aggregator and discriminator of stimuli, and it initiates useful goal-directed behavior that serves the interests of the organism. In the case of humans, the PFC is disproportionally larger than those of even close evolutionary relatives and the case can easily be made that this difference is clearly concomitant with the far superior cognitive and behavioral capabilities of humans.

Finally, this document is not intended to answer all questions or provide a definitive answer regarding the basis of PDD responses and involvement of the PFC. Instead it is merely a summary of the current information available at the present time regarding the anatomical and neurological foundations of attention, decision making, and physiological responses to PDD test stimuli. More will undoubtedly be learned in the years ahead, and it remains likely that the complexity of the brain is such that our knowledge may be forever incomplete. The current task is to continue learning through original research and through the synthesis of information from related fields of study. In terms of structure, function, and ethnology, the importance of the PFC in future PDD research is more than justified.

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