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Review Article

Functional Characteristics of The Cingulate Cortex of The Brain

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Abstract

The anterior cingulate cortex (ACC) is part of the brain's limbic system. This article discusses how the ACC is involved in a circuit related to attention, which serves to regulate both cognitive and emotional processing. Neuroimaging studies showing that specific regions of the ACC are engaged in cognition and emotions are reviewed and linked to findings indicating that error negativity is dependent on affect and motivation. Additionally, the development of the emotional and cognitive roles of the ACC is discussed, along with how the success of this regulation in controlling responses may correlate with the size of the cingulate gyrus. Finally, some theories on how different subdivisions of the ACC may interact with other cortical structures as part of the circuits involved in regulating mental and emotional activity are considered.

Kew Words: cingulate cortex; limbic system; cognitive abilities

Introduction

The study of the influence of the cingulate cortex on cognitive abilities is an important area of neuropsychology and cognitive science. The cingulate cortex, located in the medial part of the frontal and parietal lobes, plays a key role in regulating emotional states, decision-making, and information processing. According to recent studies, disruptions in the functioning of the cingulate cortex may be linked to various cognitive disorders, such as depression, anxiety disorders, and attention deficit syndrome. Understanding the mechanisms through which the cingulate cortex influences cognitive processes allows for a deeper theoretical understanding of brain function and the development of more effective methods for diagnosis and therapy [12-19]. Furthermore, in the context of rapid technological advancement and increasing informational load on individuals, the study of cognitive functions is becoming increasingly relevant. Explaining the role of the cingulate cortex in these processes could aid in creating programs to enhance cognitive abilities and prevent cognitive fatigue [1-3].

Thus, the investigation of the relationship between the cingulate cortex and cognitive abilities holds both theoretical and practical significance, opening new horizons for further research in neuropsychology and related disciplines [4-10].

Objective: The aim of this study is to identify and analyze the influence of the cingulate cortex on human cognitive abilities. The goal is to assess the relationship between the function of the cingulate cortex and manifestations of cognitive disorders.

Methodology: The basis of this research is a review of contemporary foreign and domestic literature on the subject.

Results of the Study and Discussion: The structure of the human brain, which has recently attracted significant interest among specialists in cognitive and neurocognitive research, is the cingulate cortex (the cortex of the cingulate gyrus), located on the medial surface of the brain, between the corpus callosum and the cingulate sulcus [20-21]. This area of the brain, as a component of the limbic system, receives afferent signals from the anterior group of thalamic nuclei, while efferent signals from the cingulate cortex project to the parahippocampal gyrus and onward to the hippocampus. Additionally, the cingulate cortex has numerous bidirectional connections with the frontal, parietal, and occipital cortices of the cerebral hemispheres [15].

In terms of cytoarchitectonics, the cingulate cortex is quite heterogeneous. According to the classification by C. Brodmann, it is divided into seven areas: 23, 24, 26, 29, 30, 31, and 33. However, due to the difficulty of visually distinguishing the exact boundaries between some areas on tomograms, recent classifications have identified only three main divisions of the cingulate cortex: the anterior (areas 24 and 33), posterior (areas 23 and 31), and retrosplenial (areas 26, 29, and 30) cortices. Sometimes, the posterior cingulate cortex is further divided into ventral (area 23) and dorsal (area 31) parts [14-16].

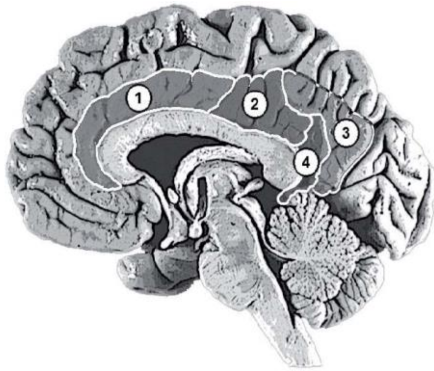

Figure 1: Divisions of the cingulate cortex:

1 – anterior (areas 24 and 33);

2 – posterior ventral (area 23);

3 – posterior dorsal (area 31);

4 – retrosplenial (areas 26, 29, and 30) cortex

The anterior cingulate cortex (ACC) is located around the rostral part of the corpus callosum. According to the projection directions, the ACC is divided into "affective" and "cognitive" components. The affective part of the ACC includes areas 25, 33, and the rostral parts of area 24 (according to Brodmann), which have extensive connections with the amygdaloid complex, the gray matter of the periaqueductal region, and the motor nuclei of the brainstem. This part of the ACC is involved in the formation of emotional states, the evaluation of motivational content and emotional valence of internal and external stimuli, as well as the expression of internal states. The cognitive part of the ACC includes areas 24 and 32 (according to Brodmann) and regulates a number of processes, primarily goal-directed behavior [12-18]. In depressive syndrome, the functional connectivity between the rostral ACC and the amygdala significantly increases only during negative self-evaluative processes, alongside a decrease in structural connections between these structures. Additionally, in depression, there is a reduction in functional connections between the rostral ACC and the dorsolateral prefrontal cortex (PFC), as well as between the latter and the dorsal ACC, while the functional connectivity between the dorsal and rostral ACC is significantly increased. This enhances functional activity and prevents the deactivation of the rostral ACC and amygdala, making it impossible to correct negative emotional states [7-14].

First and foremost, the level of activity in the ACC increases in situations of conflictual choice, high probability of making an error, and directly upon making an error. This has been demonstrated in numerous electrophysiological and functional tomographic studies. Thus, the key functions of the ACC include error detection, conflict monitoring, and action regulation [10-15].

Emotion self-regulation is a conscious and voluntary process influenced by numerous factors, including mood and competing regulatory demands. The amygdala is a key limbic structure that plays a central role in emotions. The cingulate cortex projects to both the amygdala and the prefrontal cortex. The response to emotional stimuli is controlled by a "top-down" process of emotion regulation from several areas of the frontal cortex [20]. It should be noted that the functional role of the cingulate cortex remains controversial, despite the large number of publications and various hypotheses put forward within them. The anterior part of the cingulate cortex has been studied in the most detail. Numerous studies have shown that activity in the anterior cingulate cortex is observed when performing tasks that require voluntary control of activity, including error detection, conflict monitoring, and/or attention switching, as well as in tests involving the executive component of working memory. Clinical data on damage to this area of the brain in humans and experimental data from animals also indicate that damage to the posterior cingulate cortex is associated with difficulties in performing tasks that require cognitive control. Studies using morphometric analysis suggest that patients with schizophrenia often exhibit a reduction in the volume of the anterior cingulate cortex [14-20].

The posterior cingulate cortex has been studied significantly less, with mentions of this part of the brain occurring in publications almost six times less frequently than mentions of the anterior cingulate cortex. It is known that in healthy individuals, strong activation in the posterior cingulate cortex is observed when retrieving memories from autobiographical episodic memory. Moreover, when retrieving information from episodic but not autobiographical memory, activation in this area of the brain is not observed. Additionally, it has been shown that activation of the posterior cingulate cortex also occurs during the recognition of familiar words, objects, or places. In the posterior cingulate cortex of macaques, so-called "risk neurons" have been identified, which activate when the monkey chooses a risky option, and the level of activation correlates with the degree of risk. Electrical stimulation of these neurons during a risk-related choice led to the subjects choosing a less risky option in the subsequent trial [3-11].

Anomalies in the posterior cingulate cortex (PCC) are often associated with cognitive impairments that include memory function (e.g., Alzheimer's disease, depression), attention (e.g., traumatic brain injury, ADHD), and issues with balancing internal and external thinking (e.g., schizophrenia, autism). These observations suggest that this region plays a key role in cognitive function. Early theories emphasized the role of the entire cingulate gyrus in emotions. Although the PCC responds to emotional stimuli, it is clear that the region's role in cognition extends far beyond emotional processing. The region has extensive connections with heteromodal associations and paralimbic areas, suggesting that it is well-positioned to integrate and influence higher-level information processing [17-20].

The PCC is viewed as a key structure for both arousal and awareness. Relatively high levels of metabolism in the PCC and functional connectivity are associated with a normal conscious state. In contrast, during low states of arousal and awareness, including deep sedation, activity in the PCC, measured by both absolute blood flow and functional connectivity, decreases. Metabolism and connectivity in the PCC are also low in a vegetative state and increase as patients regain consciousness [12-16].

Activity in the PCC is also sensitive to changes in awareness associated with sleep. A stepwise decrease in connectivity between the PCC and prefrontal areas tracks changes in arousal levels that occur in different sleep states. Similarly, under propofol anesthesia, both metabolism in the PCC and functional connectivity decrease more than in many other brain regions. More complex analyses of causal interactions between brain areas (effective connectivity) suggest that the reduction in consciousness observed during propofol sedation is related to the loss of normal descending cortico-cortical connectivity from the dorsal anterior cingulate cortex to the PCC. Thus, changes in arousal and awareness across various states are linked to alterations in neuronal activity in the PCC and its interactions with other brain areas.

As for the functional role of the retrosplenial cingulate cortex, studies investigating this area of the brain are particularly rare. It is known that damage to this area results in severe anterograde amnesia. Additionally, there is evidence suggesting the involvement of this brain region in emotional processes; for example, activation in this area is observed when subjects perceive emotionally charged words. There are also reports of activation in this region of the cerebral cortex during spatial navigation. When memorizing unfamiliar routes in three-dimensional space, activation occurs in the hippocampus and/or parahippocampal gyrus, whereas familiar locations show activation in the retrosplenial cortex. One case is described involving a patient with a hemorrhage in the left retrosplenial area who lost the ability to navigate in space but performed quite successfully on tests of spatial reasoning [16-18].

Recently, the method of magnetic resonance morphometry (MRM) has been actively used to study the role of various brain structures in cognitive processes. For example, numerous data have been obtained regarding the relationship between the volume of the hippocampus, as well as its various regions, and memory processes. However, in the study of the cognitive functions of the cingulate cortex, morphometric analysis is, unfortunately, used only in clinical research [9-17].

Conclusion:

Although much remains to be learned, it is clear that the cingulate cortex plays an important role in mediating cognitive influences on emotions. As noted above, excessive or insufficient activation of certain subregions appears to be associated with specific psychopathologies. This is not surprising, as impaired ability to regulate affect is present in many psychiatric disorders. A better understanding of the specific roles that various functional subregions play in emotional regulation may provide insights into both pathophysiology and potential treatment methods.

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