ARTIGO DE REVISÃO

THE ROLE OF THE CINGULATE CORTEX IN WORKING MEMORY, A LITERATURE REVIEW

O papel do córtex cingulado na memória de trabalho, uma revisão de literatura

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ABSTRACT

The cingulate cortex is responsible for being involved in cognitive functions such as attention and memory. Physiologically, this region receives and sends information through afferent and efferent pathways, respectively via the thalamus and parahippocampal gyrus. Working memory is a topic of significance for study, as it guides daily activities and human cognition. It is important to note that there are various types of memory, classified based on types and subtypes, but two definitions are particularly relevant. These are the nature of memory, which is subdivided into declarative (storing explicit knowledge) and non-declarative or procedural (responsible for memorizing implicit content); and the time of information retention, which has three types of memory classifications: operational, short-term, and long-term. The occurrence of deficits that compromise these functions directly impacts the individual's quality of life. This study is a narrative literature review, which investigated through the DeCS/MeSH descriptors "cingulate cortex," "memory," and "neural pathways." The cingulate cortex, located in the limbic lobe, is involved in action, emotion, and memory. It is present in a region composed of structures responsible for various functions, such as the hippocampus, amygdala, orbitofrontal cortex, playing distinct roles in its anterior and posterior anatomical portions. The former is related to reward neural circuits and subsequent emotions, while the latter establishes, through circuits connecting the mentioned areas and structures, a connection with memory. The cingulate cortex appears to be directly linked to cognitive activities, emotional control, influence on psychiatric disorders, and seems to have a direct impact on working memory. It is important to emphasize that this structure showed a functional association with the frontal gyrus and parietal lobe; therefore, it is still not clear which structures independently perform each action.

RESUMO

O córtex cingulado é responsável por estar envolvido em algumas funções cognitivas como atenção e memória. Pela fisiologia, esta região recebe e envia informações, pelas vias aferentes e eferentes, respectivamente pelo tálamo e giro para-hipocampal. A memória de trabalho é um tema de significância para estudo, visto que, orienta as atividades diárias e o cognitivo do ser humano. A ocorrência de déficits que comprometem essas funções impactam diretamente na qualidade de vida do indivíduo. O presente estudo trata-se de uma revisão narrativa da literatura, o qual pesquisou por meio dos descritores DeCS/MeSH "cingulate cortex" e "memory" e "neural pathways" . O córtex cingulado, localizado no lobo límbico, está envolvido na ação, emoção e memória. Estando presente numa região composta por estruturas responsáveis por diversas funções, como hipocampo, amígdala, córtex orbitofrontal, desempenha papéis distintos em suas porções anatômicas anteriores e posteriores, a primeira relacionada a circuitos neurais de recompensa e emoções subsequentes e a segunda por estabelecer, à partir de circuitos conectando as áreas e estruturas mencionadas com a memória. O córtex cingulado parece estar diretamente ligado às atividades cognitivas, controle emocional, influência em distúrbios psiquiátricos, e aparenta ter impacto direto na memória de trabalho. É importante ressaltar que, esta estrutura apresentou associação funcional com o giro frontal e lobo parietal, portanto, ainda não está claro quais estruturas isoladamente realizam cada ação.

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INTRODUCTION

The cingulate cortex is responsible for being involved in cognitive functions such as attention and memory. Physiologically, this region receives and sends information through afferent and efferent pathways, respectively via the thalamus and parahippocampal gyrus. The anatomy of this structure is challenging to visualize through imaging, despite its cells being differentiated into seven Brodmann areas. In tomography, it is divided into three major regions – anterior, posterior, and retrosplenial – for easier identification. However, some authors further subdivide the posterior cingulate cortex into ventral and dorsal regions [1].

Recent studies, conducted using magnetic resonance imaging (MRI), evaluated the function of the frontoparietal region and its relationship with working memory. The results showed a direct connection between the anterior cingulate cortex (ACC) with the middle frontal gyrus (MFG) and the superior parietal lobule (SPL). It was also observed that the cortex regulates its connectivity with these regions depending on the task being performed – whether at rest or during a memory task [2].

Therefore, it is understood that if there is trauma, neurodegenerative disease, or any damage to the cingulate cortex, it can result in various cognitive losses, including memory, motivation, social behavior, and language/ speech production. An triggering event is the Frontal Lobe Syndrome, which affects the frontal lobes, essential for many human behaviors such as decision-making and interactions. Working memory is a significant topic for study, as it guides daily activities and human cognition. The occurrence of deficits that compromise these functions directly impacts the individual's quality of life, emphasizing the importance of understanding this direct relationship between its role and the cortex. However, despite research investigations into this relationship, there is still no consensus in a single study on the subject, highlighting the need for a literature review on the topic, synthesizing and evaluating relevant evidence [3].

METHODS

This study is a narrative literature review that conducted research using the DeCS/MeSH descriptors 'cingulate cortex,' 'memory,' and 'neural pathways,' combined with the boolean operators 'AND' and 'OR,' for the search on PubMed and ScienceDirect databases. The time frame for the search was from 2013 to 2023. In this way, 224 articles were found, according to inclusion criteria, including English language, publication period, full-text availability, and relevance to the guiding question. Ultimately, 78 articles were analyzed, of which 9 were selected to compose this review.

RESULTS

This study comprised an analysis of 9 articles, with one from 2017 (11%), one from 2018 (11%), one from 2019 (11%), two from 2020 (22%), one from 2021 (11%), two from 2022 (22%), and one from 2023 (11%).

EM ANEXO

DISCUSSION

The cingulate cortex, situated in the limbic lobe, is involved in action, emotion, and memory. Existing within a region composed of structures responsible for various functions, such as the hippocampus, amygdala, and orbitofrontal cortex, it plays distinct roles in its anterior and posterior anatomical portions. The former is related to reward neural circuits and subsequent emotions, while the latter establishes connections with memory through circuits connecting the mentioned areas and structures. Emphasizing the results related to the anterior cingulate cortex, it is evident that it influences working memory, whether related to trauma, as discussed by , or task attribution and form. Broadly, imaging studies available in the literature on the cingulate cortex or the limbic lobe, along with the results obtained from the discussed studies, highlight the significant connection between the cingulate cortex and working memory [4,5].

It is apparent that the role of the cingulate cortex in working memory goes beyond simply assessing normal states. The role of the anterior cingulate cortex and its correlations with dysfunctions, such as psychiatric disorders. Considering the wide range of imaging examinations available, it is possible to relate the anterior cingulate cortex and its various interactions with neural circuits related to higher functions. The need for advancement in investigations, considering the structural and functional heterogeneity of the region, with more precise models of the relationship between the anterior cingulate cortex and the diversity of disorders and cognitive functions, is elucidated [6].

The study involved testing subjects in two variants of a working memory task, one with high attention demands and the other with memory retrieval, denoted as repetition, detection, and comparison tests. It was possible to relate patterns of functional connectivity to behavior, including brain-behavior correlations in the analysis. An ST-PLS analysis of initial behavior was also conducted to identify task-dependent changes in functional connectivity and their relationship with behavior, along with a second-order random effects analysis using contrast coding for the interaction of test type and condition using SPM99. According to the research, the anterior cingulate cortex is involved in attention and memory processes, and its contribution to these processes is shaped by changes in regions functionally connected to it. The pattern of functional connectivity and its relationship with memory performance were different between tasks, leading to changes in

the anterior cingulate cortex's contribution to attention and memory-oriented performance. The standard condition of the second task, related to memory, was significantly more error-prone than the other three conditions. Thus, the results support the hypothesis that the shift in attention bias toward memory is achieved through changes in interregional interactions or functional connections. The regions functionally connected to the anterior cingulate cortex and the relationship of these activity patterns with memory performance were completely different between tasks. In the standard task, the pattern is related to a speed and accuracy trade-off, while the uniquely signaled connectivity pattern is only related to better accuracy. It is suggested that the anterior cingulate cortex's contribution to attention and memory-oriented performance is similarly altered due to these changes in functional connectivity patterns. Therefore, it is concluded that, as the results indicate, the functional role of a region depends on the other regions it is related to, and a region may exhibit similar activity patterns between tasks but be part of different networks, producing different behavioral outcomes [7.8.9].

Although there are guiding responses, the specific activities of the cingulate cortex related to working memory, as well as its activity related to different states and situations, such as more complex work tasks, psychiatric disorders, and various types of trauma in the region, are not yet fully understood.

CONCLUSION

The cingulate cortex appears to be directly linked to cognitive activities, emotional control, influence on psychiatric disorders, and seems to have a direct impact on working memory. It is important to note that this structure has shown functional association with the frontal gyrus and parietal lobe; therefore, it is still not clear which structures individually perform each action. The gathered data suggest the crucial connection of the cingulate cortex with working memory, as supported by imaging studies confirming this relationship.

In parallel, it is important to assess beyond the state of normality, as dysfunction in the cingulate gyrus can compromise an individual's functionality, influencing their daily activities. Therefore, even though there are numerous studies on the addressed topic, it is still necessary to evaluate the specific relationship of the cingulate cortex connected with working memory to understand how different states, such as trauma to this structure, impact this activity.

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Observação: os/(as) autores/(as) declaram não existir conflitos de interesses de qualquer natureza.

Figure 1 -Characterization of studies according to authorship, year of publication, periodical, language and object of study.

No.	TITLE	AUTHORITY	BASIS	YEAR	COUNTRY	MAGAZINE
1	**Anterior cingulate cortex causally supports flexible learning under motivationally challenging and cognitively demanding conditions**	BOROUJENI et al., 2022	PubMed	2022	UK	PLOS Biology
2	Anterior cingulate cortex differently modulates frontoparietal functional connectivity between resting-state and working memory tasks	DIN; ZHANG; BISWAL, 2020	PubMed	2020	USA	Human Brain Mapping
3	Persistent Working Memory Impairment Associated with Cerebral Infarction in the Anterior Cingulate Cortex: A Case Report and a Literature Review	KOBAYASHI et al., 2021	PubMed	2020	Japan	Internal Medicine
4	Working Memory From the Psychological and Neurosciences Perspectives: A Review	CHAI; HAMID; ABDULLA, 2018	PubMed	2018	Malaysia	Frontiers in Psychology
5	The cingulate cortex and limbic systems for emotion, action, and memory	ROLLS E, 2019	PubMed	2019	Germany	Brain Structure and Function
6	Mania-related effects on structural brain changes in bipolar disorder - a narrative review of the evidence	ABÉ et al., 2023	PubMed	2023	USA	Nature - Molecular Psychiatry

7	Neuropathways of theory of mind in schizophrenia: A systematic review and meta-analysis	WENG; LIN; AHORSU; TSANG, 2022	ScienceDirect	2022	China	Neuroscience & Biobehavioral Reviews
8	The link between optimism bias and attention bias: A neurocognitive perspective	KRESS; AUE, 2017	ScienceDirect	2017	Switzerland	Neuroscience & Biobehavioral Reviews
9	Behavioral and neurophysiological differences in working memory function of depressed patients and healthy controls	NIKOLIN; TAN; MARTIN; MOFFA; LOO; BOONSTRA, 2021	ScienceDirect	2021	Australia	Journal of Affective Disorders

Figure 2 -Description of the objective and results of the sample studies according to authorship.

No.	GOAL	CONCLUSION
1	Investigate the role of the anterior cingulate cortex and striatum in flexible learning under motivationally challenging and cognitively demanding conditions.	The anterior cingulate cortex plays a crucial role in flexible feature-value learning when defeat experiences impose a motivational challenge and when uncertainty about the relevance of objects is high. The striatum, on the other hand, does not appear to play a significant role in these processes.
two	To identify the brain regions that modulate functional connectivity between frontoparietal regions during resting state and working memory tasks and whether the modulatory interactions of frontoparietal regions are consistent across different conditions.	The anterior cingulate cortex modulates functional connectivity between the right middle frontal gyrus and the right superior parietal lobule differently in resting state and working memory tasks. Increased anterior cingulate cortex activity is associated with decreased functional coupling between the right middle frontal gyrus and right superior parietal lobule in the resting state, while it is associated with increased functional coupling in the 2-back condition, in memory tasks. of work. The study suggests that anterior cingulate cortex modulations in frontoparietal connectivity have functional significance in supporting working memory and other executive functions.
3	To report the case of a 52-year-old man who presented with sudden onset permanent working memory dysfunction due to limited infarction of the anterior cingulate cortex and review the literature on the neural network associated with the anterior cingulate cortex and its role in the formation of working memory and in executive function.	It suggests the presence of a brain function associated with the anterior cingulate cortex, highlighting the importance of considering the neural network associated with it and its role in the formation of working memory and executive function. However, interpretation is limited based on this single case, and more case reports are needed to gain a better understanding.
4	It aims to refine and unite scientific knowledge about working memory, presenting theoretical models of working memory and discussing neural patterns and brain regions involved in working memory between healthy and diseased brains	Working memory is a crucial cognitive function that lays the foundation for many other cognitive controls in humans, and decoding the mechanisms of working memory is believed to be the first step in facilitating the understanding of other aspects of cognition.

5	Provide a new conceptualization of the connectivity and functions of the cingulate cortex in emotion, action, and memory	The cingulate cortex has several different functions, which may be related to the connections of its different parts and are important in emotion, episodic memory and learning the results of action, in addition to being related to other limbic structures, including the hippocampus, and the functions of different neocortical areas.
6	To review and summarize longitudinal structural MRI studies that relate imaging results to manic episodes in patients with bipolar disorder while seeking to increase understanding of the consequences that manic episodes can have on neuroanatomical structures, identify possible contributing factors and propose a model describing the pathogenesis of mania.	Bipolar disorder is associated with structural abnormalities of the brain, predominantly observed in the prefrontal and temporal cortex, cingulate gyrus, and subcortical regions, suggesting an association of bipolar disorder with aberrant brain changes, including deviant decreases and increases in morphometric measures. It proposes a model of prefrontal cortical trajectories in relation to the occurrence of manic episodes and emphasizes the necessary prevention of manic episodes.
7	Investigate and synthesize the possible tasks of theory of mind neuropathways in patients with schizophrenia using neuroimaging techniques.	Patients with schizophrenia showed deficits in neural lymph nodes related to default mode and salience networks during theory of mind tasks and provides initial evidence for a better understanding of social cognitive deficits in schizophrenia in a comprehensive and dynamic approach, and allows the exploration of cost-effective diagnostic and treatment tools.
8	Establish a framework of neurocognitive processes that may influence or be influenced by biased optimistic expectations and stimulate future research in the field.	Studying these causal relationships between cognitive biases reveals important information not only about normal functioning and adaptive neural pathways in maintaining mental health, but also about the development and maintenance of psychological illnesses, thus contributing to treatment effectiveness.
9	Clarifying the contribution of functional deficits in subprocesses in Major Depressive Disorder by varying cognitive load during a working memory task.	Individuals with Major Depressive Disorder have deficits in working memory, which is associated with generalized psychomotor slowing of working memory processes. However, the neural pathways necessary for the cognitive processes of attention, maintenance and updating are relatively preserved in depressed individuals.