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Assessment of creative thinking and executive functions in patients with frontal lobe meningioma

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Abstract

Objective: *To describe the effect of a pathology such as a meningioma-type tumor in the frontal lobe on executive functions (EF) and creative thinking, as well as determining if differences are found according to their hemispheric location and by frontal regions (medial, dorsolateral and orbitofrontal).* **Methods:** *12 patients with frontal meningioma and 12 controls were evaluated with EF tests. For creative thinking, the Torrance Test of Creative Thinking (TTCT) was used in its two verbal and figural dimensions.* **Results:** *In the comparison between patients and controls, no significant differences were observed in the scores of the TTCT. In the EF, differences were found in the components of visuospatial working memory, semantic fluency, inhibition, flexibility, abstraction, and processing speed. Regarding the laterality of the tumor, patients showed a greater deterioration in flexibility and inhibition components when the tumor was located in the left hemisphere. According to the frontal regions, when the tumor was located in the dorsolateral and orbitofrontal regions, it impaired performance in cognitive flexibility and decision-making. In the properties of elaboration and abstraction of titles of the figural scale of the TTCT, patients presented poor performance when the tumor was located in the dorsolateral region, compared to the medial region. Significant relationships were found between visuospatial working memory and the properties of the creative thinking test.* **Conclusions:** *Changes were observed in patients with frontal tumors in the evaluated processes due to the structural and functional compromise caused by its location.*

Keywords: *Creative thinking. Executive function. Pre-frontal cortex. Laterality. Meningioma.*

Evaluación del pensamiento creativo y funciones ejecutivas en pacientes con meningioma del lóbulo frontal

Resumen

Objetivo: *Describir el efecto de una patología como un tumor tipo meningioma en el lóbulo frontal, sobre las Funciones Ejecutivas (FE) y el pensamiento creativo. Así como, si se encuentran diferencias según la localización hemisférica y por regiones frontales (medial, dorsolateral y orbitofrontal).* **Métodos:** *Se evaluaron 12 pacientes con meningioma frontal y 12 controles con pruebas de FE, y para pensamiento creativo se utilizó el Test de Torrance de Pensamiento Creativo (TTPC) en sus dos dimensiones verbal y figural.* **Resultados:** *En la comparación entre pacientes y controles, no se observaron diferencias significativas en las puntuaciones del TTCT. En el EF, se encontraron diferencias en los componentes de memoria*

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de trabajo visoespacial, fluidez semántica, inhibición, flexibilidad, abstracción y velocidad de procesamiento. En cuanto a la lateralidad del tumor, los pacientes mostraron un mayor deterioro en los componentes de flexibilidad e inhibición cuando el tumor se localizaba en el hemisferio izquierdo. Según las regiones frontales, cuando el tumor se localizaba en las regiones dorsolateral y orbitofrontal, perjudicaba el rendimiento en flexibilidad cognitiva y toma de decisiones. En las propiedades de elaboración y abstracción de títulos de la escala figural del TTCT, los pacientes presentaron un pobre rendimiento cuando el tumor se localizaba en la región dorsolateral, en comparación con la región medial. Se encontraron relaciones significativas entre la memoria de trabajo visoespacial y las propiedades del test de pensamiento creativo. **Conclusiones:** *Finalmente, se observaron cambios en los pacientes con tumor frontal en los procesos evaluados, debido al compromiso estructural y funcional que ocasiona su localización.*

Palabras clave: *Pensamiento creativo. Función ejecutiva. Corteza pre-frontal. Lateralidad. Meningioma.*

Introduction

Creativity, as a cognitive process, is studied based on creative or divergent thinking[1]. It has two defining characteristics: the ability to produce responses that are both novel (original, rare, and unexpected) and appropriate (adaptive and useful according to the task constraints)[2]. Thanks to advances in neuroimaging techniques, the involvement of the pre-frontal cortex (PFC) in creativity has been documented[3-5]. This may be because the PFC regulates all higher cognitive functions, also known as executive functions (EF).

Much of our knowledge of cognitive processes has been obtained by studying individuals who have suffered damage in structures of the brain. It is no different for the issue of creativity. Lesions in the medial area (mPFC) can produce a decreased creative drive. The importance of the dorsolateral area (DLPFC) for working memory and flexible problem-solving suggests a greater role in creative skill, while orbitofrontal (oPFC) lesions may have a partly opposing effect[6]. Besides, in the study by Perfil'ev et al.[7], left pre-frontal damage showed a tendency to decrease verbal creativity and the fluency component of visual creativity.

Therefore, the purpose of this study was to describe the effect of frontal damage on verbal and figural creative thinking and EF. Although several studies have attempted to determine the participation of the PFC and each of its areas, they all have methodological deficiencies. In some, the type of pathology studied has generalized effects due to diffuse deterioration, which makes it difficult to establish a relationship with a specific area. Examples of this include reports on patients with neurodegenerative diseases[8] or brain lesions such as head injury, strokes[9], and surgery for epilepsy or brain tumors[7-10]. Another issue is that the pre-frontal areas have not yet been delimited, so it is not possible to know the specific participation of each one.

Materials and methods

Participants

Patients with meningioma-type tumor in the frontal lobe were recruited from the National Institute of Neurology and Neurosurgery (NINN) in Mexico City, Mexico, where they had received medical attention and were within the surgical protocol for tumor resection. The diagnosis was made according to the histopathological report performed on the biopsies of patients. They were evaluated before treatment (surgery, chemotherapy, or radiotherapy). Furthermore, healthy control participants matched by age, gender, and education were evaluated. The exclusion criteria applied were as follows: concomitant neurological or psychiatric diseases, antecedents of drug abuse, visual impairment, severe language deficits, and motor limitations that might affect their ability to perform creative tasks.

Instruments

Creative thinking was assessed using the two scales of the Torrance Test of Creative Thinking (TTCT): figural (TTCT-F)[11], and verbal (TTCT-V)[12], using the validated Spanish version in both cases[13]. The equivalent A and B forms were applied. TTCT generates scores for the following dimensions of the creative process. For the verbal scale: (1) fluency, that is, the number of relevant responses defined in terms of the requirements of the specific tasks or activities; (2) flexibility, or the number of different categories represented, which measures the ability to move from one conceptual field to another; and (3) originality, which reflects the number of unusual responses, understood as statistically-infrequent ideas (Fig. 1A). For the Figural (graphic) scale, meanwhile, the properties assessed were: (1) fluency; (2) originality–as defined above–(3) elaboration, or the number of details in each response; (4) resistance to

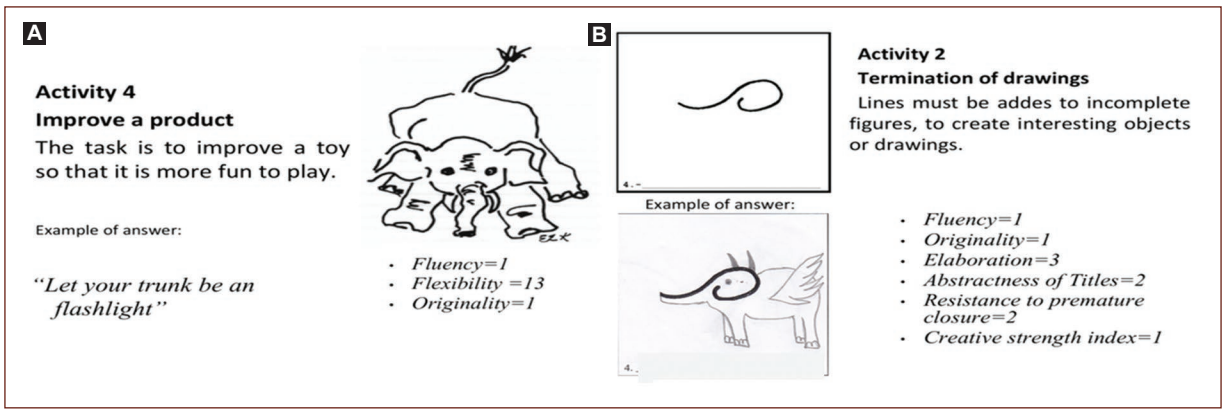

Figure 1. A and **B**: examples of items, response and score of the verbal and figural Torrance Test of Creative Thinking.

pre-mature closure, which reflects the ability to remain open to uncertainty; and (5) abstractness of titles, or the degree of abstraction versus concreteness. In addition, scores are given for such creative strengths as emotional expressiveness, storytelling articulateness, movement or action, expressiveness of titles, synthesis of incomplete figures, unusual visualization, internal visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy (Fig. 1B).

To evaluate executive functioning, the neuropsychological tests described in table 1 were used.

Procedure

A descriptive-correlational study was carried out, which was approved by the bioethics committee of the NINN (protocol number 49/12). All participants were given an informed consent to sign (Table 1)[14]. The main components related to the functioning of the PFC are shown below, as well as the neuropsychological instruments for its evaluation and its specific location.

To determine the frontal area involved by the meningioma (due to compression effect of the cranial region) in the medial, orbital, and dorsolateral regions, the hemispheric laterality, and the measurement of volume and edema, brain images were analyzed by structural Magnetic Resonance Imaging (sMRI) using 8-channel Magnetic Resonance GE Signa Excite II, Tesla 3 equipment. Volumetry of the tumor mass was obtained using the program IPlan® (BrainLAB, Heimstetten, Germany). Sequence T1 and T2 MRI was utilized. For the anatomical mapping of lesions, the study had the support of expert neuroradiologists from the NINN who were blind to our hypotheses.

To identify the specific area of the frontal lobe where the tumor was located, the following criteria were considered:[15] (1) mPFC area, where damage involved the area between the superior frontal sulcus and medial orbitofrontal gyrus (Brodmann areas 8,9,10,11,12,24,32); (2) oPFC area, when the tumor was located between the medial sulcus of the H-shaped gyrus and the lateral surface of the third frontal convolution (Brodmann areas 10,11,13,47); and (3) dlPFC area, where the tumors affected the region from the superior frontal sulcus to the inferior frontal sulcus (Brodmann areas 8,9,10,11,44,45,46,47). To obtain the volume (space occupied by the tumor) and the edema (pathological increase in the amount of water in the brain with an increase in the volume of the brain parenchyma), the dimension of the lesion in cm^3 was recorded in the longitudinal, transverse and coronal planes, and its volume was calculated using the volumetric measurement technique.

All patients were evaluated individually from 1 to 30 days before tumor resection, in a consulting room or in the NINN hospitalization area; both spaces had optimal environmental conditions and no distractions. In the case of the control group, these were healthy participants who met the selection criteria. They were evaluated individually in one to two sessions, in an isolated room under suitable conditions and without environmental distractions.

Statistical analysis

All statistical analyses were carried out using the software IBM Statistical Package for the Social Sciences (SPSS) 21 (SPSS Inc., Chicago, IL, USA). The level of statistical significance was set at p = 0.05 for

Table 1. The main components related to the functioning of the PFC are shown below, as well as the neuropsychological instruments for its evaluation and its specific location (*adapted from Climent-Martínez et al.*[14])

Components	Test	Frontal cortex areas involved
Working memory (verbal and visuospatial)	Indirect visual and Verbal spans	PFC dorsolateral
Access to semantic and phonological memory	Verbal fluency	PFC dorsolateral Medial frontotemporal cortex
Planning	Tower of London (TOL-DX)	PFC dorsolateral
Alternating/divided attention Processing speed	Trail Making Test (TMT)	Frontoparietal circuit White substance
Inhibition	Stroop test	Anterior cingulate cortex PFC orbital
Flexibility	Wisconsin Card Sorting Test (WCST)	PFC dorsolateral PFC medial
Decision making	Iowa Gambling Task (IGT)	PFC orbital PFC dorsolateral
Abstraction	Kenningar Examination	PFC medial PFC dorsolateral

PFC: pre-frontal cortex.

all analyses. The Mann-Whitney U test was performed to evaluate differences between tests of creative thinking and EF of patients with frontal brain tumors and control participants, as well as in the laterality of the tumor. The location by frontal region (medial, orbital, and dorsolateral) was compared by means of the Kruskal-Wallis test. In case statistically significant differences were found, *post hoc* analyses were carried out using the Mann-Whitney U test to determine where these differences came from. To know if executive functioning and creative thinking are related to each other and to volume and peritumoral edema, the Spearman correlation coefficient was used.

Results

Sample description

The sample consisted of twelve patients (9 women and 3 men with a mean age of = 44.2 years, standard deviation [SD] = 10.5, and mean education = 10.9 years, SD = 4.1) and twelve control participants (9 women and 3 men with mean age = 43.4, SD = 10.8 and mean education = 11.3 years, SD = 3.4). The application of the Mann-Whitney U test found no significant differences in age ($p = 0.862$) or education ($p = 0.726$) between patients and control participants that might have affected their performance on the tests.

In terms of laterality, in six patients the tumor was in the right hemisphere, in four it was in the left hemisphere, and in two it had spread bilaterally, predominantly in the left hemisphere in terms of total volume. The Mann-Whitney U test did not detect any significant differences ($p > 0.05$) in performance between patients with tumors located in the left hemisphere and those with bilateral extension, so it was decided to put them together in the same group.

Regarding the localization of the tumors by the pre-frontal region due to compression effect and regardless of laterality, four were found in the medial area, four in the orbital area, three in the dorsolateral area, and one spread through the three areas but with predominance in the dorsolateral area, so that patient was placed in this final group.

Comparisons of creative thinking and EF between patients and health controls

In creative thinking, no significant differences were found in TTCT verbal and figural performance ($p > 0.05$). Regarding EF, in general, patients presented a lower performance in comparison to the control group in all the tests, showing a lower score, presenting more errors, and taking longer to perform the tests.

In the following processes, a disturbance in the performance of patients is observed according to the

Table 2. Significant differences in executive function tests between patients and control group

Test		Patients	Control group	Mann–Whitney U test	
		Mean (standard error)		Z	p
Fluency	Semantic score	14.4 (1.66)	20.6 (1.11)	–2.7	0.007**
Tower of London (TOL-DX)	Execution time	389.9 (66.49)	201.2 (25.33)	–2.60	0.009**
	Resolution time	478.3 (85.57)	245.5 (25.76)	–2.43	0.015*
Trail making test	Time B	292.5 (53.08)	117.3 (26.03)	–2.89	0.004**
	Total errors B	4.1 (1.26)	0.9 (.452)	–2.16	0.030*
Stroop test	Word-color score	28.2 (3.68)	43 (1.72)	–3.21	0.001**
	Interference score	–3.1 (2.11)	7 (1.26)	–3.18	0.001**
Indirect visual span	Score	4 (0.389)	5.1 (0.288)	–2.02	0.043*
Examination Kenningar	Score	5.6 (0.514)	7.8 (0.808)	–2.29	0.022*
Iowa gambling task	Time	552.2 (78.77)	365.8 (26.07)	–1.96	0.05*

*Significant at the level 0.05 (bilateral); **Significant at the level 0.01 (bilateral).

normalized scores: Semantic fluency, planning (movements more than the TOL-DX test), inhibition (interference score of Stroop test), and speed processing (execution and resolution times, TMT A and B times). It should be noted that in flexibility (assessed by the Wisconsin Card Sorting Test [WCST]), both patients and controls maintain an impaired performance.

Significant differences were found in visuospatial working memory, semantic fluency, processing speed (execution and resolution time of TOL-DX test, TMT B time and execution time in the Iowa Gambling Task), inhibition (interference scores of Stroop Test), and abstraction (assessed by the number of correct answers in the Kenningar examination). No differences were observed in verbal working memory, phonological fluency, or flexibility (WCST) (Table 2).

Volume and peritumoral edema

The average volume of tumors was 47.9 cm^3, in a range of 0.72-108.6 cm^3. Regarding peritumoral edema, an average of 16.7 cm^3 was observed, in a range of 0.19-88.1 cm^3. In addition, a grouping was carried out according to the size of the volume and edema of the meningiomas into small (< 10 cm^3), medium (between 10.001 and 50 cm^3) and large (> 50 cm^3).

In the evaluation of creativity, no significant relationships were found with the size of the volume and peritumoral edema. Regarding executive functioning, with respect to volume, it presents a moderate negative correlation with the planning process (total number of correct answers in the TOL-DX test) with a $\rho = -0.7$ ($p = 0.02$). While edema, processes such as phonological fluency ($\rho = -0.7$, $p = 0.03$), present a moderate negative correlation, and processes such as planning and inhibition, evaluated by the type I error (move more than one ball at a time) ($\rho = 0.6$, $p = 0.05$) of the test of TOL-DX test, present a moderate positive correlation.

Hemispheric differences

Upon comparing creative thinking in relation to the laterality of tumors, no significant differences associated with hemispheric tumor location were found.

For the EF tests, significant differences were found in the inhibition process (interference score of the Stroop test) ($Z = -2.647$, $p = 0.01$), with a higher mean score (better performance) when the tumor was in the right hemisphere. Similarly, in cognitive flexibility, it was observed that patients whose tumor was in the left hemisphere carried out the test in the greatest number of attempts possible, while those with a tumor in the right hemisphere required fewer attempts ($Z = -2.286$, $p = 0.02$).

Differences among the pre-frontal areas (medial, orbital, dorsolateral)

With respect to creative thinking, the statistical analyses of the Kruskal–Wallis test and subsequent *post*

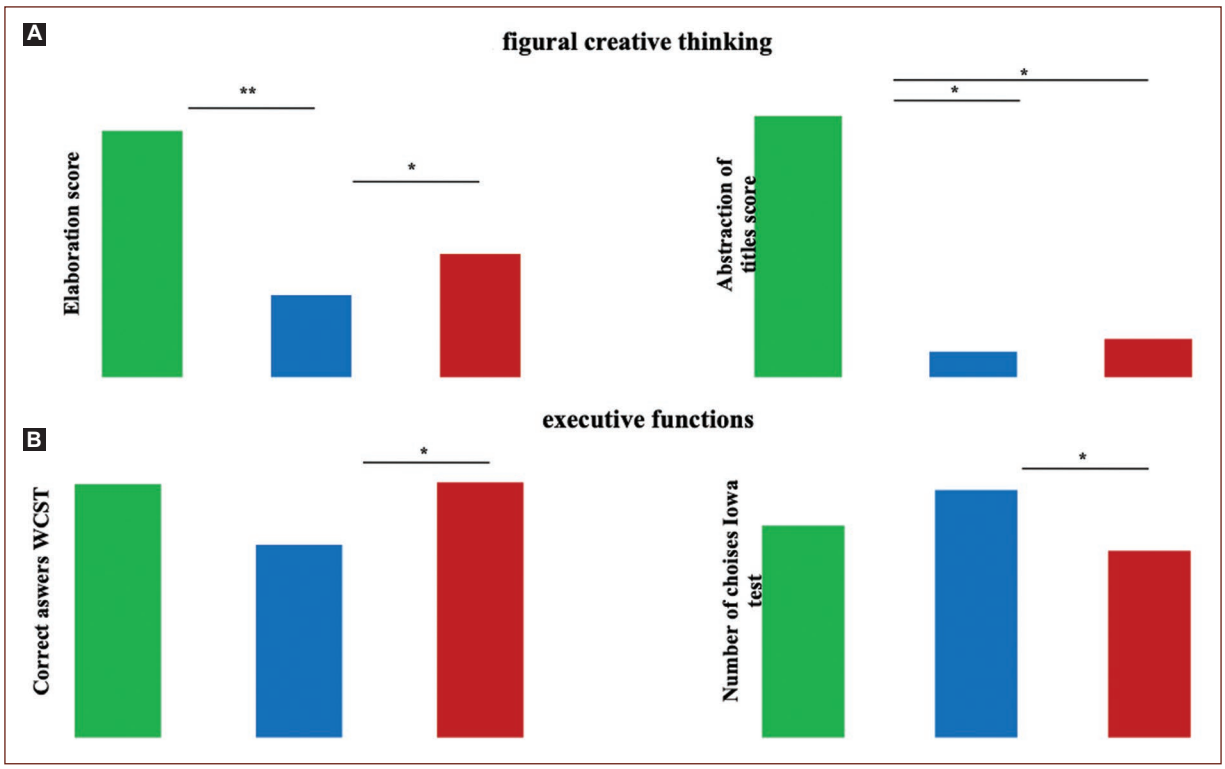

Figure 2. A and **B:** differences among the pre-frontal areas in figural creative thinking and executive functions in patients with meningioma.
*Significant at the level 0.05 (bilateral).
**Significant at the level 0.01 (bilateral).

hoc analyses with the Mann–Whitney U test did reveal significant differences in two of the properties of the figural TTCT, namely, elaboration ($X^2 = 8.261$, $p = 0.02$) and abstraction of titles ($X^2 = 7.700$, $p = 0.02$), where patients with tumor in the dorsolateral region showed a lower score in elaboration compared to the other two regions (medial $Z = –2.477$, $p = 0.01$ and orbital $Z = –2$, $p = 0.05$). Patients whose tumor developed in the medial region obtained a higher score in the abstraction of titles property compared to the dorsolateral ($Z = –2.323$, $p = 0.02$) and orbital ($Z = –2.309$, $p = 0.02$) (Fig. 2A).

In EF, significant differences were found in cognitive flexibility. Through the number of correct answers in the WCST ($X^2 = 5.857$, $p = 0.05$), it is observed that patients with tumors in the dorsolateral frontal region have a lower number of correct answers, compared to those with a tumor in the other regions. Such differences are significant with patients with a tumor in the orbital region ($Z = –2.309$, $p = 0.02$), who have the highest scores. In decision making, differences were found between the three regions ($X^2 = 6.575$, $p = 0.03$); specifically, those whose tumor was in the dorsolateral region presented a greater number of choices of deck 3 (advantageous) in the test Iowa compared with patients whose tumor was in the orbital region ($Z = –2.309$, $p = 0.02$) (Fig. 2B).

Relation between creative thinking and EF

A correlation was found between EF and creative thinking, only in the visuospatial working memory component (inverse Corsi cubes). A moderate positive correlation is observed between this component of EF, both with verbal creativity (in its properties of fluency, flexibility, originality, and the total score), and with figurative creativity (Figural Creativity Index).

Discussion

The purpose of this study was to determine the effect of frontal damage on verbal and figural creative thinking and EF. To accomplish this, patients with frontal pathologies caused by tumors were evaluated and their

performance was compared to that of a control group. It is well-known that patients with meningioma-type tumors have focal deficits that are location-dependent[16,17]. Therefore, this is a type of pathology that offers an ideal paradigm for studying the impact of a lesion in a specific area on cognitive processes.

There were no significant differences in the scores on the two TTCT scales (verbal and figural) between patients and controls. Thus, it is possible to infer that the involvement of other cerebral regions, both cortical and subcortical, are indispensable in this process[18-20], though other studies have emphasized the participation of such brain networks as the default mode and frontoparietal control networks[10,21,22].

However, it is important to keep in mind that the meningioma-type tumors diagnosed in the participants of this study are benign and characterized by slow growth patterns, which means that they can become quite large before causing symptoms. In addition, the brains of participants had been adapting to the growth of the mass, and a plasticity effect had occurred, which can induce a functional reorganization and may be a possible explanation to why no significant changes were observed in the assessment of creative thinking in patients with frontal tumors. It is believed that this explains why neurological deficits do not appear immediately with the onset of pathological lesions, even when they develop within the so-called eloquent areas[23]. This is, then, a possible explanation of why significant changes were observed in the assessment of creative thinking in patients with frontal tumors.

Regarding the components of executive functioning, it was found that the presence of a tumor causes deficits in the execution of patients since in general terms their performance was lower compared to the control group. The results obtained agree in part with data from previous studies[24], where it was found that patients with frontal meningiomas have deficits in working memory, fluidity, shifting, and flexibility. However, it should be noted that in the present investigation, other components of EF were also evaluated, such as: planning through the TOL-DX test, inhibition with the Stroop test, abstraction through the Kenningar Examination for the exploration of metaphorical thinking and decision-making with the IGT, in which significant differences were found compared to the control group, for which these results highlight the importance of deepening the study of EF and in these patients.

In this study, it was found that both the volume and the peritumoral edema presented in the patients showed variability, which was reflected in the executive functioning tests, but not in the creativity evaluation. As to the impact of tumor laterality on creative thinking, no hemispheric differences were found. This result was not unexpected, since creativity also leads to producing useful, relevant, and effective ideas, a process that is driven by the left hemisphere. This result agrees with the findings reported by Mihov et al.[25] who did not observe any differences in the predominantly right hemispheric activation on verbal tasks compared to figural tasks. Finally, according to Lindell[26], creativity is not a lateralized function but rather derives from the interaction and integration of information across the left and right hemispheres.

Significant differences were found in terms of tumor laterality though, since it was found that those that developed tumors in the left hemisphere present deficits in cognitive flexibility (through the WCST test), which is justified by the participation of this hemisphere, specifically of the DLPFC, in tasks that require changing a scheme of action or thought in relation to the evaluation of its results[27]. Significant differences were also found for this same hemisphere in the inhibition process (assessed by the Stroop test), since the patients showed a lower capacity for resistance to interference, which is consistent with studies that indicate that the inhibitory processes that occur during mental tasks that require cognitive activity produce activations lateralized to the left hemisphere[28].

With respect to the differences among the areas of the PFC, it should be noted that significant variations were found in the properties of elaboration (development, ornamentation, or beautification of an idea) and abstraction of titles (i.e., the ability to capture the essence of the information involved) of the figural scale of the Torrance test. In general, observations showed that the patients with tumors in the dorsolateral area had lower performance than those with tumors in the other regions (medial and orbital). This finding can be explained by the fact that alterations in this area are related to deficits in cognitive processes that could impair performance on such creative tasks as abstraction, working memory, flexibility, and fluency, among others[29]. Specifically, a study that analyzed the cerebral bases of originality found that patients with right mCPF lesions obtained lower scores for originality on creativity tests[9], indicating the participation of this area in this component of creativity. Another study, this one of patients with focal frontal lesions, revealed critical prefrontal nodes that were related to the ability to generate and combine remote semantic associations when damage occurred in the pre-frontal medial and pre-frontal

rostrolateral regions, respectively[10]. Finally, according to Gonen-Yaacovi et al.[30] this area appeared to be organized along a rostro-caudal axis, with rostral regions involved in combining ideas creatively and more posterior regions active in freely-generating novel ideas.

Regarding the differences between the regions of the PFC in the EF, it was observed that patients with a tumor in the dorsolateral region show greater deficits in cognitive flexibility tasks (WCST), which corresponds with previous studies[31]. Patients whose tumor was found in the orbitofrontal region presented a lower number of advantageous choices (choice from Deck 3), which agrees with what has been reported in the literature, which states that whose region participates in the processing of related information to the reward[32].

According to the relationship between EF and creative thinking, significant relationships were also found in visuospatial working memory, with both verbal and figural TTPC properties; therefore, this process is considered crucial for our ability to see connections between items that are apparently not connected and to separate elements, since the essence of creativity is being able to integrate and/or recombine elements in a new and different way, and to consider something from a new perspective[33], for which working memory is required in the creative process.

One of the limitations of this study was the small sample size, which has an impact in terms of lower statistical power; therefore, it is necessary to analyze a larger number of patients, since this would allow us to obtain more representative data that can be generalized to the population. In addition, every effort was made to ensure that the participants fulfilled all the necessary requirements and that the tests applied were the ideal ones for evaluating the processes proposed in this research.

Conclusions

There were no differences between patients and controls in verbal and figurative creative thinking, so in addition to the frontal regions, the participation of other cortical and subcortical regions is indispensable to this process. However, some processes were more vulnerable to such damage, for example, those primarily concerned with this area, such as some EF components.

Patients with a tumor in the left hemisphere present less execution in the processes of flexibility and inhibition. Nevertheless, this study did not find evidence that the laterality of the tumor impacted creative thinking. Therefore, this process is derived from the interaction and integration of information in the left and right hemispheres.

With respect to the areas of the PFC, these can play a critical role in creativity, and this emphasizes the importance of determining the participation of these areas of the PFC in greater detail. Significant relationships were found between EF components, mainly visuospatial working memory and the properties of the creative thinking test.

Finally, a developing tumor can invade and destroy the brain tissue in the area in which it is located, creating a specific deficit in the patient which depends on the tumor location. Therefore, this type of tumors that cause alterations in the proper functioning of the frontal lobes, indirectly helps us to better understand the organization of creative thinking in this region.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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Ethical disclosures

Protection of humans and animals. The authors declare that no experiments on humans or animals were performed for this research.

Confidentiality of data. The authors declare that they have followed their center's protocols on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the corresponding author.

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