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Final report on creativity as assessed by functional magnetic resonance imaging and SCAMPER tool[1]

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Resumen
Para describir la creatividad así como la operación y la activación cerebral y se llevó a cabo en la R. Argentina. El estudio fue codirigido por un neurólogo y un educador musical y envolvió un equipo interdisciplinario. Una herramienta desarrollada y validada en trabajos previos ((S.C.A.M.P.E.R) ha sido aplicada para evaluar la actividad creativa de un grupo de veinticuatro estudiantes voluntarios de un grado universitario en musicoterapia. Un paradigma de resonancia funcional magnética por imágenes que abarcó los estímulos rítmicos auditivos y la recogida de las respuestas creativas de los sujetos en tareas repetitivas y creativas fue diseñado e implementado. Nuestros resultados sugieren que los sujetos con mejores performances en la evaluación de la fluidez y la flexibilidad, mostraron en ambos hemisferio cerebrales áreas activas asociadas con procesos cognitivos, emocionales y perceptivos ,mientras que los sujetos con performances más pobres activaban áreas cerebrales relacionadas sobre todo con integración sensorio-motora predominantemente unilateral.

Abstract
This text introduces the Based partially on the Torrance model to describe creativity and his approach to its evaluation a research oriented to evaluate creative performance and functional brain activation was run in Argentina. The study was co-leaded by a neurologist and a music educator, involving multidisciplinary teams. A tool developed and validated in a previous work (S.C.A.M.P.E.R) has been applied to assess creative performance in a group of 24 voluntary students from a university grade Music Therapy career. A functional magnetic resonance imaging paradigm, involving simple audible rhythmical stimuli and collection of subject responses to creation and repetition tasks, was designed and then implemented. Our results suggested that subjects with better performances on fluidity and flexibility assessments showed in both cerebral hemispheres active brain areas associated to cognitive, emotional and perceptual processes whereas subjects with poorer performances activated brain areas mostly related with complex sensorimotor integration, predominantly unilaterally.

Palabras clave
Creatividad; Patrones rítmicos; fMRI; S.C.A.M.P.E.R; Evaluación

Keywords
Creativity; Rhythmical patterns; fMRI; S.C.A.M.P.E.R; Assessment

[1] Este informe se articula con el trabajo de Violeta Schwarcz Lopez Aranguren que se incluye en este mismo monográfico

1. Introduction

Creativity is a mental process that involves generation of new, original and attractive ideas. Only few studies in neuroimaging have investigated neural networks related to creative tasks. In the field of music, only two studies (Bengtsson et al., 2007; Limb & Braun, 2008) have examined the neural mechanisms that underlie generation of new musical ideas. However, none of them has differentiated the creative level of the subjects and even less sought the possible existence of differences among the neural networks and their correlation with the level of creativity.

2. Objetive

To analyze functional activity of the brain during rhythm productions of control subjects, and to evaluate correlations with their creative performance.

3. Methods

3.1. Subjects

Twenty four voluntary, right-handed healthy subjects (mean age 21 ± 2 years; 9 males) were recruited for this study. All participants were students sharing the same courses of the "Music Therapy" career at Universidad del Salvador (USAL) and having similar level of musical education; according to curricular evaluations and current assessment methodologies.

First they were divided into two groups through performing rhythmical tasks after hearing a rhythmical pattern; products were described and analyzed with the criteria provided by the S.C.A.M.P.E.R concerning flexibility and fluidity. These two groups were organized as "high" and "low creative level" .

All participants gave written informed consent in accordance to the declaration of Helsinki, and the protocol was reviewed and approved by the Local Ethics Committee at FLENI Institute.

3.2. Paradigm

We analyzed the subjects´ brain activity using functional magnetic resonance imaging (fMRI) techniques during rhythm fragments production, and analyzed activations grouping according to fluidity and flexibility performances.

During the fMRI scans, subjects were lying supine in the scanner room provided with headphones, a compatible button-response box and a non-magnetic visualization mirror mounted in the head-coil. A total of 200 images were acquired while subjects were performing the paradigm.

The paradigm consisted on the randomized presentation of brief predefined audible stimuli rhythms via the headphones (monotonal percussion patterns @ a440; 4 seconds long) while one word instruction was presented in a specially designed back projected screen visualized through the head-coil mirror. Two tasks were instructed to follow after listening to the patterns: Create and Repeat. Subjects performed the instructed tasks by pressing the response button comfortably placed at their laps with a single finger movement, playing the role of executing the same percussion instrument listened in the previously presented rhythms.

Auditory return was implemented and a synthesized audio feedback with the same characteristics to the originally presented stimuli was listened during each task execution. Briefly, subjects listened to their productions as similar or modified patterns, with the same pitch, volume and sound characteristics with respect to the original rhythmical stimuli.

During the first task (Create) participants were instructed to create a new rhythm based in the previous listened stimulus. During the second task (Repeat), they had to reproduce the stimulus instead.

Task duration was configured to allow 10 seconds either in the creation or repetition stages, in order to give subjects enough time to execute their productions.

Regarding to visual instructions, they were restricted to the minimum necessary stimuli, so that tasks were announced by a single word displayed on the screen: LISTEN, CREATE or REPEAT. All subjects were clearly instructed on all the paradigm process prior to the study, so each participant was familiar with all the visual instructions and audible stimuli.

The paradigm presentation, including visual and audio stimuli, response management and scanner synchronization was implemented using Presentation v14.4 software (Neurobehavioral Systems, Inc.) running in a dedicated notebook computer used for standard fMRI procedures in the control room.

The magnetic resonance images were acquired in a 3 Tesla General Electric HDx scanner with an 8 channel head-coil. Changes in blood-oxygenation-level-dependent T2* signal was measured using a gradient echo-planar imaging (EPI) sequence. Twenty four contiguous slices were taken in the AC-PC plane (TR: 2.3 s, TE: 35 ms, flip angle: 90°, FOV: 24 cm, 64 x 64 pixels per inch matrix, voxel size = 3.75 x 3.75 x 4). A structural MRI was acquired with the fast SPGR-IR sequence (120 slices, 1.6-mm thick slices, TR 12.956 ms, TE 6.1 ms, flip angle 15°, FOV 24 cm, 512 x 512 matrix). One session of 200 volumes was taken per subject.

3.3. Performance analysis

All subjects' performances during the fMRI session were recorded in a text file containing time stamps of the subject responses. For each task, we extracted the time table and converted it to a rhythm sequence. The creations were then assessed by two independent evaluators (both of them with university degree musical background) using the SCAMPER method (Bengtsson et al., 2007; Carlsson et al., 2000). By means of the resulting punctuations applied to all the creation tasks, fluidity and flexibility parameters were computed for each subject; subsequently, grouping according to those creative skills was performed.

3.4. Functional MRI Data analysis

Image processing was carried out using SPM2 (Wellcome Department of Cognitive Neurology, London, UK) implemented in MATLAB 7 (Mathworks Inc., Sherborn, MA, USA). The imaging time series was realigned to the first volume and spatially normalized to the stereotactic space of Talairach and Tournoux (1988) using the Montreal Neurological Institute reference brain then the volumes were spatially smoothed by an sotropic Gaussian kernel of 8mm at full width half-maximum and high pass filtered during analysis. Individual analysis was computed using the general linear model including all the conditions and correction for head movements.

According to subjects' performance on fluidity and flexibility, we created two groups for each parameter based on subjects scores; defining lower fluidity and flexibility groups and the higher counterparts groups. Then we performed statistical group analysis for Create vs. Repeat tasks.

4. Results

4.1 Creation assessment

For the fluidity parameter we obtained a distribution of values ranging between 19 and 43 units. With those data we built a histogram from which we created two groups: one formed by 11 subjects with values below 32 (mean 24.5 ± 3.9) defined as "less creative on fluidity" group (LCfy) and the other with values above 34 (mean 38.5 ± 3.2) formed by 13 subjects and defined as "more creative on fluidity" group (MCfy).

For the flexibility parameter the values obtained ranged from 58 to 79 units and a histogram classified the subjects in two groups: one with values below 64 (mean 61.1 ± 2.5) formed by 12 subjects defined as "less creative on flexibility" group (LCfx) and other with values above 74 (mean 76.7 ± 1.2) formed of 12 subjects defined as "more creative on flexibility" group (MCfx).

Subjects grouped according to their high or low values in fluidity scores were not necessary classified into the homologous high or low flexibility values groups, for that reason we based our analysis on the four mentioned groups: MCfy, MCfx, LCfy, LCfx. Figure 1 shows the histograms and Table 1 the performance results.

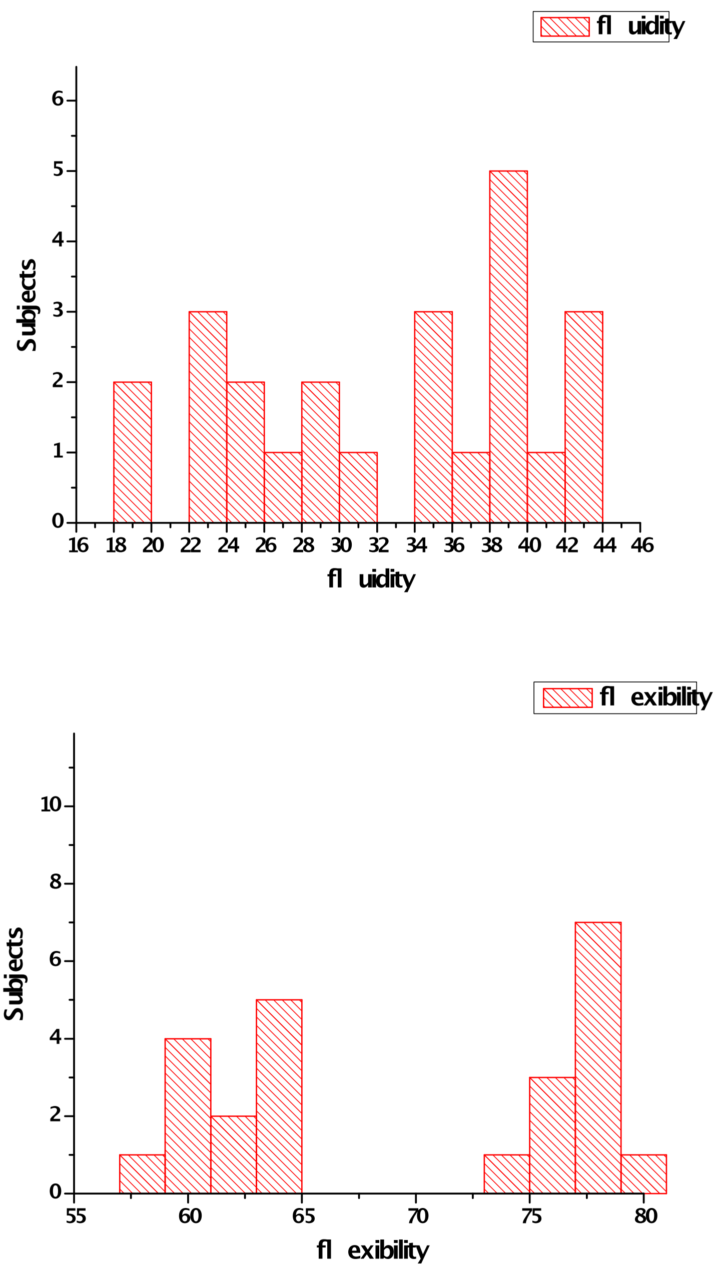

Figure 1: Histograms

Table 1:
Fluidity and Flexibility scores

Subject	*Fluidity*	*Flexibility*	*Subject*	*Fluidity*	*Flexibility*
S1	19	64	S13	34	63
S2	19	59	S14	34	77
S3	22	63	S15	36	77
S4	23	59	S16	38	77
S5	23	63	S17	39	76
S6	24	58	S18	39	76
S7	25	61	S19	39	79
S8	27	59	S20	39	74
S9	28	63	S21	41	78
S10	29	61	S22	42	77
S11	31	77	S23	43	76
S12	34	60	S24	43	77

4.2. fMRI results for create and repeat tasks

4.2.1. Random effect analysis for fluidity class groups

Group analysis for MCfy showed activation bilaterally in thalamic areas, and superior (SFG) and medial frontal gyrus (MFG); left inferior parietal lobe (IPL) and right precentral and inferior frontal gyri (IFG) as well as in the right superior temporal gyrus (STG). The analysis for the LCfy group resulted in activation in the left MFG, IPL and precuneus and a cluster in the MFG in the right side. Table 2 shows the coordinates and t-values. Images are displayed in Figure 2a and 2b.

Table 2:
Create vs. Repeat for fluidity class groups (P<0.001; uncorrected)

		Coordinates			
Regions (abbreviations)	*# voxels*	*x*	*y*	*z*	*t-value*
MCfy					
L Thalamus	760	-8	-16	8	12.93
R Thalamus	1234	16	-18	8	10.41
L Medial Frontal Gyrus	2310	-10	16	48	8.13
R SFG		10	6	76	6.42
L MFG	107	-52	24	32	7.64
L IPL	780	-40	-44	44	5.91
R precentral Gyrus	181	42	6	22	6.25
R IFG	320	48	14	-12	5.17
R Inferior Occipital Gyrus	527	44	-72	-6	5.44
L MFG	170	-36	-2	48	4.57
R STG	178	42	-42	12	5.17
R Precentral Gyrus	165	54	-2	54	5.16
LCfy					
Left MFG	1132	-36	4	52	13.4
Left MFG		-40	30	24	9.4
Left IPL	116	-40	-52	56	10.18
Right Medial Frontal Gyrus	152	18	10	52	8.82
Left precuneus	95	-28	-80	52	6.66

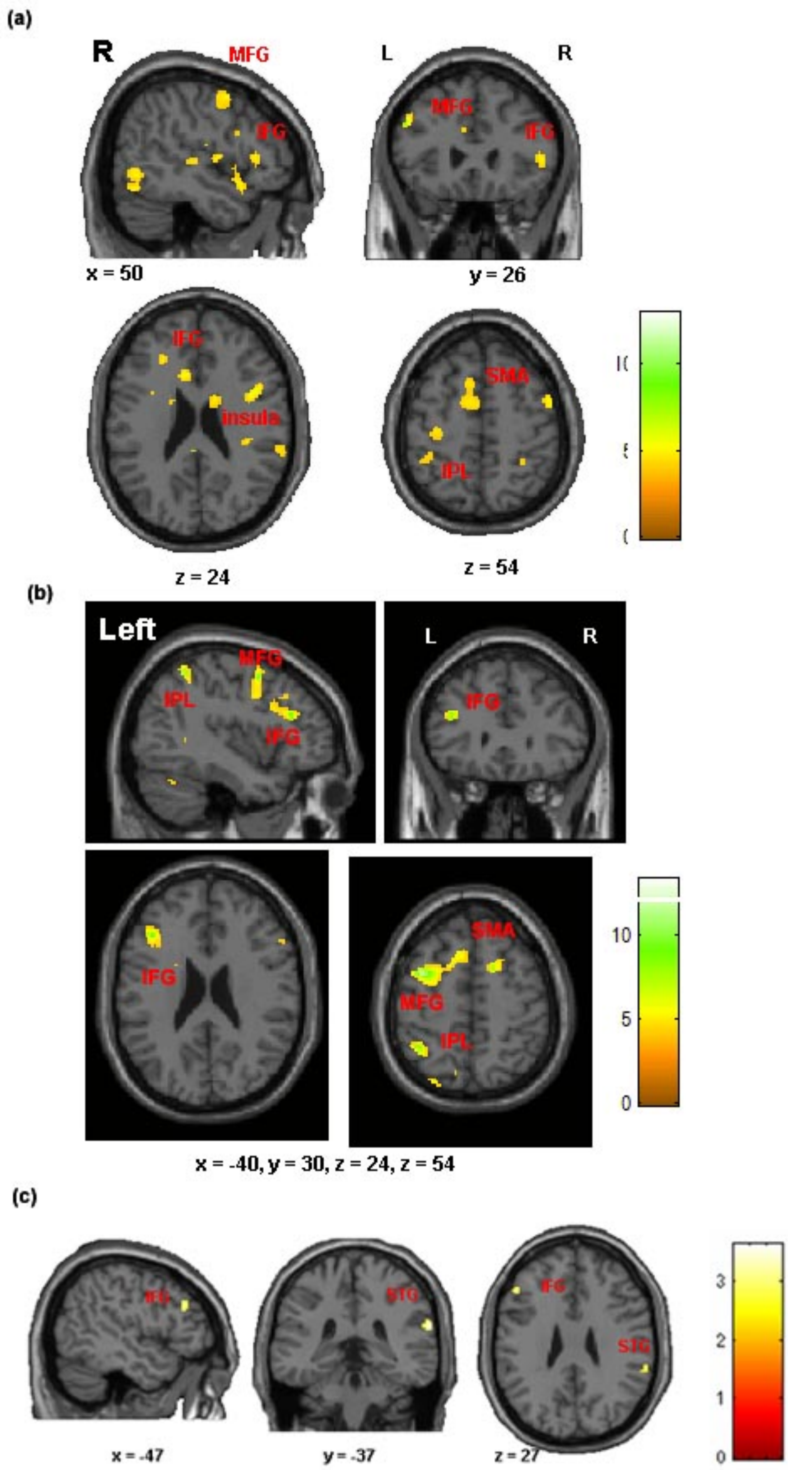

Figure 2: fMRI activity: Create vs. Repeat. Group analysis for MCy (a) and LCy (b); Two sample t test for MCy over LCy (c)

4.2.2. Comparative results for MCfy vs. Lcfy

A two sample t-test between groups revealed a major effect in frontal areas like MFG and IFG bilaterally although more intense in the right hemisphere, for the MCfy group over LCfy as well as bilateral activity in the superior temporal gyrus and middle insula. The inverse comparison, LCfy over MCfy, gave more activity in the left hemisphere mainly in the MFG and precuneus although activity in the same regions but in the right hemisphere was also found but less intense. Images are shown in Figure 2c.

4.2.3. Random effect analysis for flexibilty class groups

Random effect analysis for MCfx group showed an increment of BOLD activity, mainly in prefrontal areas like the IFG and MFG, as well as bilaterally in the insula. Activity was also presented bilaterally in thalamus and caudate nucleus, and in the left SFG. Activity for LCfx group showed fewer differences, mainly observed in the left MFG and SFG, left superior parietal lobule and precuneus (only at voxel level). Table 3 resumes the coordinates at voxel threshold ($P< 0.001$; uncorrected). Figure 3a and 3b shows the BOLD signal for MCfx and LCfx group respectively. Table 3 shows the respective coordinates and t-values.

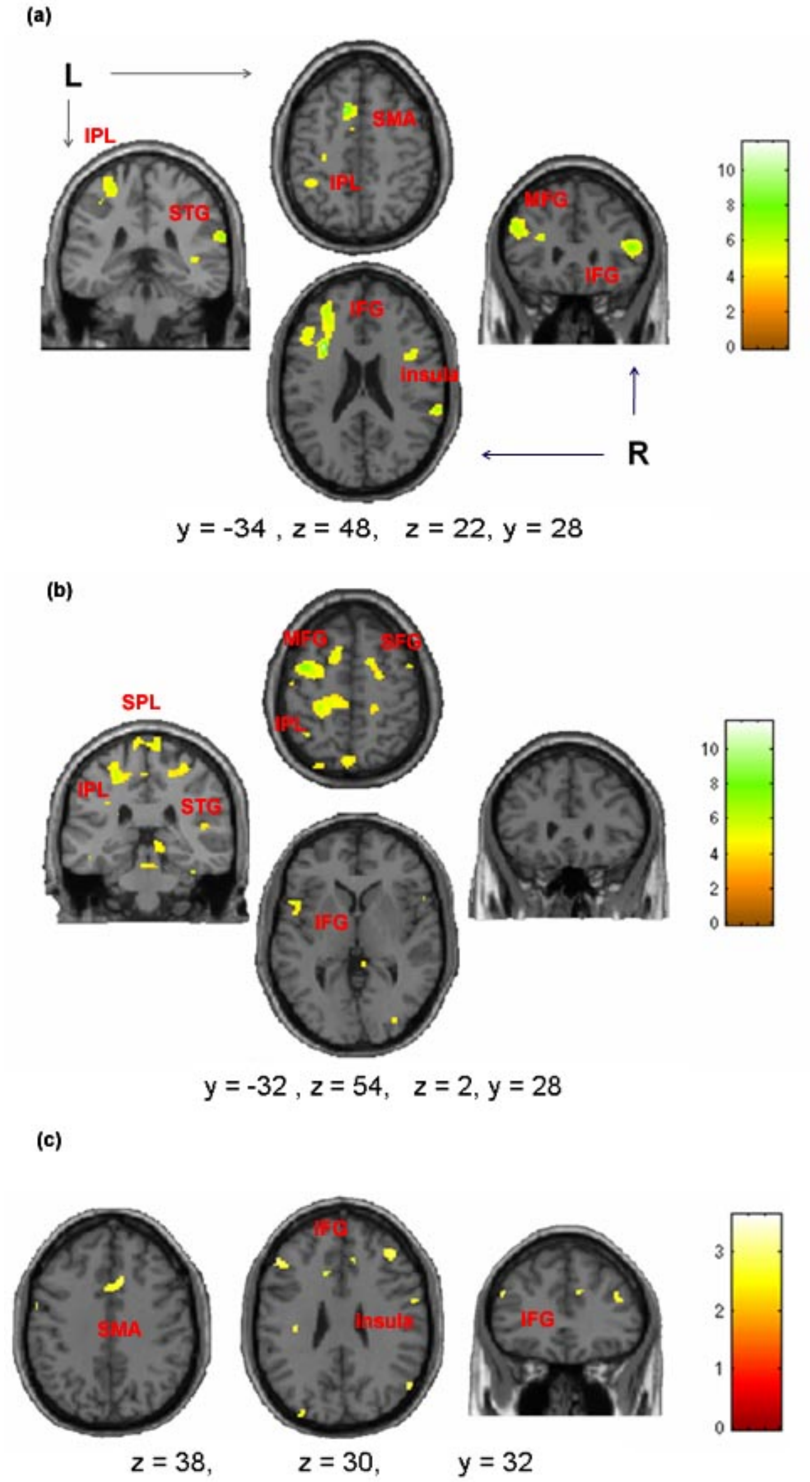

Figure 3: fMRI activity: Create vs. Repeat. Group analysis for MCx (a) and LCx (b); Two sample t test for MCx over LCx (c)

Table 3:
Create vs. Repeat for flexibility class groups. (P<0.001; uncorrected)

		Coordinates			
Regions (abbreviations)	*# voxels*	*x*	*y*	*z*	*t-value*
MCfx					
L insula	1245	-32	18	22	11.87
L IFG		-48	18	26	6.8
L MFG		-30	48	22	5.32
L SFG / Medial Frontal G.	428	-8	14	58	11.16
L Thalamus	1799	-10	-14	8	9.09
R Thalamus		18	-20	10	7.97
L Caudate		16	2	16	6.12
R Caudate		-16	0	18	6.04
R insula	1357	42	8	20	8.01
R IFG		48	28	14	7.85
R aSTS		48	14	-12	5.21
R fusiform gyrus	804	52	-66	-14	6.06
R MTG		62	-62	-2	5.69
LCfx					
L MFG	1404	-36	4	56	9.03
L SFG		-22	8	64	6.13
R Middle Occipital G	256	38	-74	-10	7.17

4.2.4. Comparative results for MCfx vs. LCfx

The comparison MCfx over LCfx revealed activity differences in frontal areas bilaterally, although the major activity was found in the right hemisphere. Active areas were located over IFG, insula and MFG. For the opposite comparison LCfx over MCfx, the activity was only found in left MFG, right precuneus and left superior parietal lobule. Images are displayed in Figure 3c.

5. Discussion

From the SCAMPER analysis of both groups of high and low level of fluidity, the behavior of the cognitive mechanisms underlying the processes of creation (and observed on the productions) have not been very different, presenting normal distributions in both groups and being similar to each other.

The creative production regarding flexibility was generated primarily based on modifications to the original stimuli and to a lesser extent by replacing some element of the original pattern. The retrogradation and inversion options over the original pattern were rarely observed, being not statistically different nor in the group of low or high level of flexibility. Besides, the differences found on the adaptation and elimination dimensions, allowed us to infer that the groups with lower levels of fluidity and flexibility were somehow fastened to the original patterns presented in the paradigm, and could make whole or partial changes, always keeping references to the original stimuli.

On the other hand, subjects with higher levels of fluidity and flexibility could introduce the elimination dimension in the original patterns, generating their own creations with low adhesion to the stimuli and performing quite original productions.

According to the random effect analysis of the fMRI, in the MCfy and MCfx cases (better performance on fluidity and flexibility) brain active areas in both cerebral hemispheres were mainly associated to cognitive, emotional and perceptual processes; while in the LCfy and LCfx cases (poorer performance on fluidity and flexibility) active areas, particularely in the left hemisphere, were linked with complex sensorimotor integration.

Our evidence seems to demonstrate that brain activations would be present in distinctive brain areas, which can be correlated to the performance level of some creativity tools; in this case to the fluidity and flexibility components of the SCAMPER assessment tool. Further research, possibly under other types of stimuli and creation environments, would be needed in order to support our results.

We believe that this research could help understand what underlies below certain complex human productions as creative behavior, and would enable us to enrich our knowledge and contributions to settings for either general or specialized education.

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