



Neural foundations of creativity: A voxel-based meta-analysis of the activations and deactivations underlying creativity across linguistic, musical, and visual domains

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ABSTRACT

The neuroscience of creativity has proposed that shared and domain-specific brain mechanisms underlie creative thinking. However, greater nuance is needed in characterizing these mechanisms, and limited neuroimaging analyses, especially regarding the relationship between the Alternative Uses Task (AUT) and other linguistic tasks, have so far prevented a comprehensive understanding of the neural basis of creativity. This paper offers to fill these gaps with a closer examination of the contributions of the specific domains and the deactivations associated with creativity. We conduct a voxel-based meta-analysis of 43 neuroimaging studies involving 1118 participants. Using Seed-Based d Mapping, we investigate the spatial activity maps in the brain associated with overall creativity and with specific domains. Our findings reveal various domain-general mechanisms related to creativity, including working memory, the ability to connect distantly related concepts, the inhibition of conventional thought, interoception, internal goal orientation, mind wandering, and mental motor simulations. We also identify domain-specific mechanisms of creativity that differ by modality. Linguistic creativity requires inhibiting typical semantic associations, musical creativity involves auditory-motor integration and spontaneous expression, and visual creativity depends on inhibiting habitual visuospatial associations. Additionally, AUT is more effective at capturing novel tool manipulation and ideation rather than elaborative creative processes, which limits its scope. This meta-analysis underscores that creativity depends on multi-component neural circuits and highlights the need for future research to report deactivations, investigate neurofeedback applications, and analyze long-term and collaborative creative processes.

1. Introduction

In recent years, creativity has drawn increasing attention from neuroscientists and behavioral scientists, largely due to its role in driving innovation across technology, science, and the arts (Hadida, 2015). Humans, by nature, are effortless conformists – a tendency reinforced by social norms and central to cultural transmission (Cubillos-Pinilla and Emmerling, 2022). Against this backdrop of habitual sameness, creative thinking stands out as both rare and cognitively demanding (Benedek et al., 2014b). Creativity, understood

as the capacity to generate ideas or products that are both novel and appropriate (that is, marked by originality and the element of surprise – Amabile, 1996; Stein, 1953, 1988), becomes vital when conventional approaches fall short. By introducing what did not exist before, its value is inherently comparative: it is measured against the absence of ideas or the reuse, imitation, or replication of existing ones. To probe the cognitive foundations of creativity, researchers have analyzed brain activity during tasks with varying creative demands.

Previous research suggests that creativity relies on domain-general mechanisms – that is, cognitive processes shared across different forms

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of creative expression, such as linguistic, musical, and visual domains (Boccia et al., 2015; Gonen-Yaacovi et al., 2013; Sawyer, 2011). These processes are not tied to the specific output of creativity but support it more broadly. Accordingly, brain regions involved in general cognitive functions are expected to show increased activation during tasks that demand higher levels of creativity.

For example, regions associated with working memory, reward evaluation, the inhibition of top-down executive control, and which enables remote associations, such as the inferior and middle frontal gyri (components of the dorsolateral prefrontal cortex), have been shown to be more active during creative thinking (de Souza et al., 2014; Ivanovsky et al., 2018; Khalil et al., 2020; Kleinmuntz et al., 2018). Similarly, areas involved in episodic memory, voluntary selection, focused attention, suppression of irrelevant thoughts, and cognitive flexibility, such as the anterior cingulate cortex and the cingulum, also show increased activity during creative tasks (Berkowitz and Ansari, 2008). These regions are key components of the executive control network (ECN).

Other brain areas that support associative memory, such as the hippocampus, parahippocampal gyrus, and temporal pole (all components of the medial temporal lobe), have also been linked to creativity (Bartoli et al., 2024; Beaty et al., 2023; Ren et al., 2023). Additionally, regions involved in contextual monitoring, self-referential thinking, goal-directed behavior, and mind wandering, such as the medial part of the superior frontal gyrus and the cingulum, which are part of the default mode network (DMN), have been associated with creativity (Giordani et al., 2023; Vartanian et al., 2022). Finally, areas within the salience network, particularly the insula, may contribute to interoception and the contextualization of creative ideas (Beaty et al., 2016; Hazelton et al., 2024).

In contrast, Sawyer (2011) calls for further investigation of domain-specific mechanisms –that is, brain activity uniquely tied to specific expressive domains. The strong link between creative performance and domain-specific components (Kaufman and Baer, 2005) suggests that different domains of creativity – such as musical, visual, or linguistic – may engage distinct neural patterns (Boccia et al., 2015; Dietrich and Kanso, 2010). Dietrich and Kanso (2010) theorized that domain-specific activity relies less on the frontal lobes, typically associated with domain-general processes, and more on the temporal, occipital, and parietal regions (i.e., TOP regions). More recently, Brown and Kim (2021) proposed that the sensorimotor areas that are already active during non-creative tasks – such as the supplementary motor area and regions of the inferior parietal lobe, including the supramarginal gyrus – enhance their activity during creative tasks.

Despite growing interest in the field and valuable insights provided by previous research, neuroimaging research on creativity remains in its infancy. Independent examinations of expressive domains reported consistent domain-general activations associated with creativity (Boccia et al., 2015; Chen et al., 2020). Even so, Chen et al. (2020) did not include all creative domains within a comprehensive meta-analysis, and Boccia et al. (2015) did not assess the extent to which individual domains contribute to domain-general activations. Nor did they examine the uniqueness of each domain after accounting for shared domain-general activity. Similarly, additional meta-analyses in specific domains such as visual creativity (Pidgeon et al., 2016; Satcheli et al., 2022) and linguistic creativity (Cogdell-Brooke et al., 2020; Kuang et al., 2022; Wu et al., 2015) lack comparisons with other creative domains and domain-general creativity, limiting the distinct characterization of brain activity associated with each domain.

Moreover, previous meta-analyses have largely overlooked brain deactivations associated with creativity. This may be partly because deactivations, which are considered more difficult to interpret than activations due to discrepancies with electrophysiological data, were therefore less reported by fMRI studies (Hayes and Huxtable, 2012). Even so, interpreting deactivations relative to a comparison condition can provide valuable insights into creativity by identifying which brain

regions need to be less active (Limb and Braun, 2008) or suppressed or actively inhibited (Liu et al., 2015) during a creative task. Understanding brain activity associated with creativity in healthy individuals can also help us understand how this process differs in pathological conditions. Metaphorically, the brain function can be likened to a grand orchestra: brain regions act as instruments, and cognitive processes as melodies. For melodies to be harmonious, some instruments must play (activation) while others rest (deactivation), and both processes are important for cognitive balance.

The Executive Control Network (ECN) and the Default Mode Network (DMN) are generally considered to operate in opposition during goal-directed tasks that involve external sensory focus. ECN activation is often accompanied by DMN deactivation or suppression relative to resting-state (Fox et al., 2005; Greicius et al., 2003). At the same time, previous research has shown activations in brain regions that belong to both the ECN and DMN during mind-wandering and creativity (Boccia et al., 2015; Chen et al., 2020; Christoff et al., 2009). Although deactivations in some DMN brain areas may reflect active suppression of internally generated thoughts and a shift of attention to the task that requires creative effort (Gordon et al., 2014; Laurent et al., 2024), they have not yet been systematically examined in creativity. Thus, examining both brain activations and deactivations could offer a more complete picture of the neural basis underlying creativity.

The Seed-based d Mapping (SDM) methodology (Albajes-Eizaguirre et al., 2019b) enables the investigation of both activations and deactivations, including within specific cognitive domains. Other meta-analytic techniques, such as Activation Likelihood Estimation (ALE), often limit this capability by requiring many studies (Brown and Kim, 2021). Previous meta-analyses may also fall short of reporting heterogeneity and publication biases. SDM addresses these limitations by incorporating effect sizes and using a signed differential mapping approach (Radua and Mataix-Cols, 2012). SDM integrates voxel- and coordinate-based data and analyses variability in effect sizes (Radua and Mataix-Cols, 2009). It controls conservatively for multiple comparisons (Shepardson et al., 2023) and assesses both heterogeneity (Garcés et al., 2021) and publication bias (Radua and Mataix-Cols, 2012). Applying SDM to creativity research in healthy individuals can reveal core neural patterns, distinguish them from pathological deviations, and inform targeted therapeutic interventions.

Over-reliance on the Alternate Uses Task (AUT; Boccia et al., 2015; Gonen-Yaacovi et al., 2013; Wu et al., 2015; Cogdell-Brooke et al., 2020), a task developed by Guilford (1967) to assess creativity, is another limitation of previous meta-analyses. AUT involves generating creative uses for everyday objects and is typically scored on fluency and originality (Ivanovsky et al., 2021). However, AUT is mainly limited to idea generation from a cognitive perspective. In contrast, other creativity tasks such as metaphor creation (Benedek et al., 2014a), anagram solving involving "aha" moments (Aziz-Zadeh et al., 2009), name invention (Fink et al., 2009b), story writing (Erhard et al., 2014; Howard-Jones et al., 2005; Shah et al., 2013), poetry composition (Liu et al., 2015), and character decomposition (Huang et al., 2015), extend beyond ideation and involve further elaboration to produce creative products (Brown and Kim, 2021). Therefore, analyzing the neural correlates of AUT separately from those of other tasks enables a more focused investigation of the ideational component of creativity and the development of a task-specific neural activity profile. While the brain activity of AUT differs from other creative tasks (Brown and Kim, 2021), research has not yet investigated the extent to which AUT contributes to overall creativity and the relationship of this task with other linguistic tasks and expressive domains. To address this oversight, we compare an AUT-focused sub-meta-analysis with broader analyses of (a) overall creativity, (b) overall creativity excluding AUT, (c) linguistic creativity, (d) linguistic creativity excluding AUT, (e) musical creativity, and (f) visual creativity.

In summary, research in the neuroscience of creativity requires greater nuance in understanding domain-general and domain-specific

brain activation patterns, including delving into the uniqueness of each expressive domain. Additionally, prior studies have largely overlooked the deactivations associated with creativity, limiting our insight into the whole neural activity landscape. Finally, the lack of further detailed neuroimaging analyses in previous research limits our understanding of the relationship between AUT and other linguistic tasks and creative domains. Our study constitutes the most extensive meta-analysis of creativity to date. To complement previous work by addressing these gaps, we use a Seed-based d Mapping (SDM) approach to conduct a whole-brain voxel-based meta-analysis of both activations and

deactivations associated with overall creativity, along with the following sub-meta-analyses: (a) overall creativity excluding AUT, (b) linguistic creativity, (c) linguistic creativity excluding AUT, (d) AUT alone, (e) musical creativity, and (f) visual creativity. In doing so, we describe activations and deactivations of overall creativity and the sub-meta-analyses. Moreover, we further quantify how each domain contributes to overall creativity and create unique brain activity maps of the expressive domains after controlling for their contribution to overall creativity.

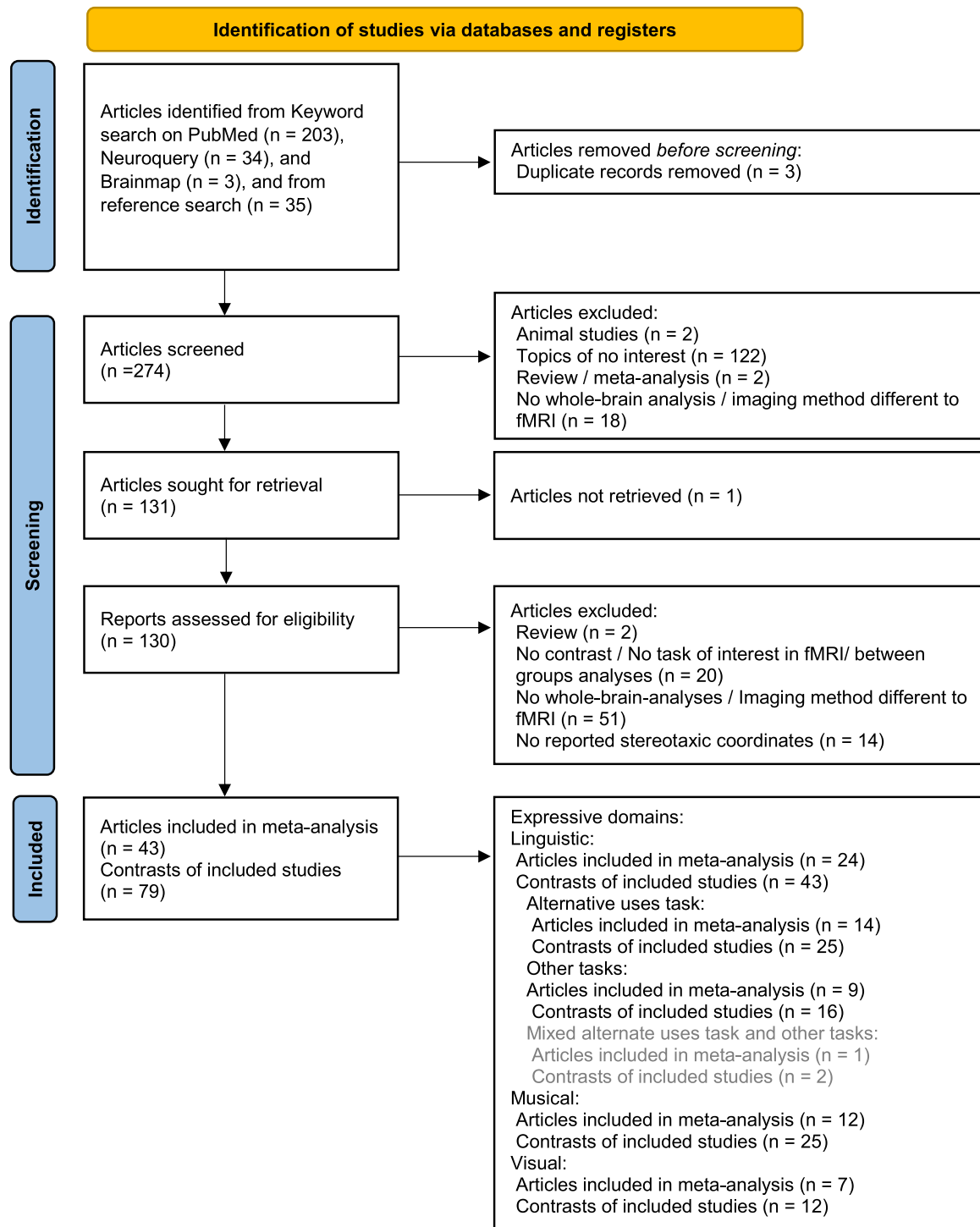


Fig. 1. The procedure of literature search and study selection. From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021;372:n71. doi: 10.1136/bmj.n71.

2. Method

2.1. Literature search and selection criteria

We performed a broad literature search via *Pubmed*, *Neuroquery*, *Brainmap*, and reference search (Fig. 1), using key words (“creative” OR “creativity” OR “idea generation” OR “idea production”, OR “divergent thinking” OR “convergent thinking” OR “ alternative uses”) AND (“fMRI” OR “MRI” OR “voxel-based” OR “voxelwise” OR “whole-brain”). The term selection allowed us to focus on articles that mention at least one cognitive task explicitly associated with creativity. The search yielded 274 articles. We adopted Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), see Fig. 1. The Table “Literature List” in the link provides detailed article titles, authors’ names, year, ID (e.g., PMID, DOI number), journal or publication name, and reason for exclusion.

2.2. Extraction and sample

Table 1 shows the 43 studies and 79 contrasts of high creative tasks versus low creative tasks, as well as the sample size, age, and sex of each of the contrasts included. The contrasts showing the activity of low creative tasks being lower than that of high creative tasks were considered as activations. The contrasts that show the activity of high creative tasks being lower than that of low creative tasks were called deactivations. Furthermore, these studies were divided into categories to perform independent sub meta-analyses: overall creativity excluding AUT ($n = 28$), linguistic creativity ($n = 24$) including one study reporting the conjunction of AUT with a metaphor production task as a high creative task, AUT ($n = 14$), and other tasks (i.e., linguistic excluding AUT, $n = 9$), visual creativity ($n = 7$), and musical creativity ($n = 12$). In total, 1118 healthy or non-diagnosed participants (Age_{mean} , standard deviation = 25.65, 6.14; Male total, percentage = 513, 45.89 %) were included in the meta-analysis. Among them, within those articles that reported demographics, 1021 (91.3 %) reported to be right-handed, 245 (21.9 %) non-medicated, 822 (73.5 %) without a history of mental disorder, 503 (44.9 %) current university students, 65 (5.8 %) art students, and 142 (12.7 %) professional artists. The supplementary material provides further details.

2.3. Meta-analytic procedure

Following the SDM protocol (www.sdmproject.com, Albajes-Eizaguirre et al., 2019b), we registered sample sizes, corrected thresholds for studies’ contrasts (z-values, p-values), and contrasts’ peaks coordinates and statistical values (t-values, p-values, z-values, F-values). Corrected contrasts thresholds ranging between $p = .005$ and $p = .001$ were set up to $z < 3.1$, and those ranging between $p = .05$ and $p = .01$ were set up to $z < 2.3$. We converted the p-values and z-values to t-values using the SDM online converter, and the f-values to t-values using the formula $t = F$. To control for Type I error, we robustly corrected all results using family-wise-error (FWE), $p < .05$ (Yeung et al., 2019; Yeung, 2024).

To increase the specificity of our results, we applied additional corrections such as Threshold-Free Cluster Enhancement (TFCE, $p < .05$) and a voxel-extent threshold of < 10 voxels (Zheng et al., 2021). If no clusters survived TFCE correction, we reported the activation results prior to applying the spatial enhancement correction and after the voxel-extent threshold of < 10 voxels (Jiang et al., 2020; Radua et al., 2012; Shi et al., 2016; Wang et al., 2018).

We reported deactivations after FWE correction. A total of 40 % of the studies lack deactivation data (28 % neglect to examine this contrast, 9 % reported non-significant differences, and 2 % reported the names of uncorrected deactivation regions but omitted coordinates; see Table 1). Deactivations analyses for the overall creativity meta-analysis (28 studies), and the sub meta-analyses: overall creativity excluding meta-analysis (20 studies), linguistic excluding AUT (5 studies), AUT (8

studies), musical creativity (9 studies), and visual creativity (5 studies); were reported as deactivations (indicating FWE-TFCE-corrected results) and as deactivations preceding spatial enhancement (indicating FWE-TFCE-corrected and voxel-extent threshold of < 10 voxels; Shuai et al., 2024). While our study uses Seed-based d Mapping (SDM), which provides robust results even with smaller study numbers (e.g., by considering effect sizes and application of the same or further corrections as ALE), we acknowledge that alternative meta-analytic approaches such as ALE typically require larger sample sizes for reliable inference. Therefore, from the standpoint of the ALE framework, our sub-meta-analyses should be interpreted as exploratory.

For each resulting peak of activation or deactivation, we obtained Montreal Neurological Institute (MNI) peak coordinates, the names of brain regions, the effect size, and the voxel (mm^3), as reported by Shen et al. (2024), Suh et al. (2019), and Zhang et al. (2020). We used automated Anatomical Labeling atlas (AAL3v1; Rolls et al., 2020) to correct mislabeling of the corpus callosum and to label the median cingulate cortex for consistency. We used Python (v3.8.18) with the NiLearn package to perform visualization of the brain maps, following neuroimaging visualization standards (Abraham et al., 2014; Baez et al., 2024; Hernandez et al., 2024; Yan et al., 2025). The code used to generate the figures is available in the project’s public repository. We then used SDM to compute heterogeneity tests, funnel plots, and publication bias tests (Duval and Tweedie, 2000; Egger et al., 1997; Higgins and Thompson, 2002).

2.4. Uniqueness of the sub meta-analyses

We used FSL (Jenkinson et al., 2012) to assess unique brain activations and deactivations in each sub-meta-analysis. Brain maps were binarized with the *fslmaths* function, and conjunction analyses were performed between the overall creativity map and each sub-meta-analysis. Unique regions were identified by subtracting the overall map from each sub-meta-analysis, and these were further compared across domains. We applied a cluster threshold of > 10 voxels to reduce false positives (Lieberman and Cunningham, 2009; Roiser et al., 2016). Cluster centroids, region labels (AAL3v1; Rolls et al., 2020), and visualizations were computed in Python (v3.8.18) using nibabel (Brett et al., 2020), NiLearn (Abraham et al., 2014), and scipy (Virtanen et al., 2020).

2.5. Voxel contribution analyses

We quantified spatial overlap between each sub-meta-analysis and the overall creativity map by computing the ratio of shared voxels and the Dice similarity coefficient (Crum et al., 2006), using the Python-based nibabel package (Brett et al., 2020). This analysis was also repeated after excluding AUT. This voxel-based method offers a more systematic and objective estimate of each domain’s contribution, reducing the risk of human error compared to manual counting of reported brain region names across studies (Brown and Kim, 2021).

3. Results

We found no overlap between activations and deactivations in either the overall or sub-meta-analyses. Table 2 presents peak activation and deactivation results (only the highest Z-value peak per region in the cluster is shown). The open-access repository provides detailed information on activation and deactivation of all clusters, including regions, coordinates, significance, cluster size, effect sizes, and voxel size of the contributing brain regions. Additionally, the same repository contains the coordinates, magnetic flux values, threshold corrections used in the original contrasts, peak statistics for each cluster, funnel plots, and full results of FWE-corrected activations and FWE-corrected deactivations before and after TFCE correction.

Table 1

Description of studies included in the voxel-based meta-analysis.

Author, Year	N	Male	Language	Age	High creative task	Low creative task	Contrasts
Linguistic creativity							
Abraham, 2012 ^{a, c}	19	8	German	22.24	Alternative uses	Object location	AUT > Object location
Abraham, 2018 ^{a, c}	102	0	German/ English	22.6 ± 2.8	Alternative uses	Object location/ 2 n-back	AUT > Object location, 2-n back
Aziz-Zadeh, 2009 ^{b, c}	10	5	English	20 – 40	Aha anagram solutions	Search anagram solutions	Aha > Search
Beaty, 2017 ^b	24	9	English	24.19	Verb generation with unstudied nouns (low constraint)	Cued recall	Cued recall > Unstudied nouns
Beaty, 2017 ^b	24	9	English	24.19	Verb generation with unstudied nouns (low constraint)	Cued recall	Un-studied nouns > Cued recall
Beaty, 2017 ^b	24	9	English	24.19	Verb generation with studied nouns (high constraint)	Cued recall	Cued recall > Studied nouns
Beaty, 2017 ^b	24	9	English	24.19	Verb generation with studied nouns (high constraint)	Cued recall	Studied nouns > Cued recall
Beaty, (2018) ^{a, c}	29	17	English	21.79	Alternative uses	Sentence semantic control condition	AUT > Sentence
Benedek, 2014 ^b	35	11	German	22.7	Alternative uses	Fixation cross	AUT > Baseline
Benedek, 2014 ^b	35	11	German	22.7	Alternative uses	Fixation cross	Baseline > AUT
Benedek, 2014 ^{a, b, d}	28	10	German	26.2	Metaphor generation	Synonym generation	Metaphor > Literal
Chen, (2023)	31	11	Chinese	19.3 ± 2.49	Uses generation (creative condition), metaphor generation (creative condition)	Uses generation (conventional condition), metaphor generation (conventional condition)	Creative > Conventional
Chen, (2023)	31	11	Chinese	19.3 ± 2.49	Uses generation (creative condition), metaphor generation (creative condition)	Uses generation (conventional condition), metaphor generation (conventional condition)	Conventional > Creative
Erhard, (2014) ^{b, c}	48	26	German	25.20 ± 1.9	Creative writing	Reading	Writing > Copying
Fink, (2009a) ^a	21	10	German/ English	24.29 ± 4.09	Alternative uses	Object characteristics	AUT > OC
Fink, (2009a) ^a	21	10	German/ English	24.29 ± 4.09	Alternative uses	Object characteristics	OC > AUT
Fink, (2009a) ^{b, c}	21	10	German/ English	24.29 ± 4.09	Name invention	Fixation cross	Name invention > Cross fixation
Fink, (2015) ^a	24	13	German	24.04 ± 2.39	Alternative uses	Instances	AUT > IT
Fink, (2015) ^a	24	13	German	24.04 ± 2.39	Alternative uses	Instances	IT > AUT
Fink, (2015) ^a	29	14	German	24.04 ± 2.39	Alternative uses	Instances	AUT > IT
Fink, (2015) ^a	29	14	German	24.04 ± 2.39	Alternative uses	Instances	IT > AUT
Howard-Jones, (2005) ^b	8	1	English	21.9 ± 2.7	Creative story generation	Uncreative story generation	Creative > Uncreative
Howard-Jones, (2005) ^b	8	1	English	21.9 ± 2.7	Creative story generation	Uncreative story generation	Uncreative > Creative
Huang, (2015) ^b	15	9	Chinese	22.36	Novel Chinese character decomposition	Familiar Chinese character decomposition	Novel > Familiar
Huang, (2015) ^b	15	9	Chinese	22.36	Novel Chinese character decomposition	Familiar Chinese character decomposition	Familiar > Novel
Huang, (2015) ^b	15	9	Chinese	22.36	Appropriate Chinese character decomposition	Inappropriate chinese character decomposition	Appropriate > Inappropriate
Huang, (2015) ^b	15	9	Chinese	22.36	Appropriate chinese character decomposition	Inappropriate chinese character decomposition	Inappropriate > Appropriate
Kleibeuker, (2013) ^a	43	21	Dutch	21.8 ± 1	Alternative uses	Object characteristics	AUT > OC
Kleibeuker, (2013) ^a	43	21	Dutch	21.8 ± 1	Alternative uses	Object characteristics	OC > AUT
Kröger, (2012) ^{a, c}	19	9	German	22.68	Alternative uses high unusuality	Alternative uses low unusuality	AUT high unusuality > AUT low unusuality
Liu, (2020) ^b	27	12	English	32 ± 12	Poem generation	Recitation	Generation > Recitation
Liu, (2020) ^b	27	12	English	32 ± 12	Poem generation	Recitation	Recitation > Generation
Mayseless, (2015) ^a	25	10	Hebrew	25.7 ± 2.3	Alternative uses	Object characteristics	AUT > OC
Mayseless, (2015) ^a	25	10	Hebrew	25.7 ± 2.3	Alternative uses	Object characteristics	OC > AUT
Shah, 2013 ^{b, c}	28	14	German	24 ± 1.9	Creative writing	Story copying	Writing > Copying
Sun, (2016) ^a	28	11	Chinese	19 ± 1	Alternative uses	Object characteristics	AUT > OC
Sun, (2016) ^a	28	11	Chinese	19 ± 1	Alternative uses	Object characteristics	OC > AUT
Sun, (2019) ^a	29	12	Chinese	19.48 ± 0.74	Alternative uses	Object characteristics	AUT > OC
Sun, (2019) ^a	29	12	Chinese	19.48 ± 0.74	Alternative uses	Object characteristics	OC > AUT

(continued on next page)

Table 1 (continued)

Author, Year	N	Male	Language	Age	High creative task	Low creative task	Contrasts
Vartanian, (2013) ^{a, c}	34	8	English	30.79 ± 7.06	Alternative uses	Object characteristics	AUT > Inter-trial interval
Vartanian, (2018) ^{a, c}	44	31	English	35.47	Alternative uses	Object characteristics	AUT > OC
Musical creativity							
Bengtsson, (2007) ^d	11	11	Swedish	32 ± 6	Musical improvisation	Melody repetition	Improvisation > Repetition
Berkowitz, (2008)	12	4	English	21.9	Musical improvisation	Pattern playing	Improvisation > Pattern playing
Berkowitz, (2008)	12	4	English	21.9	Musical improvisation	Pattern playing	Pattern playing > Improvisation
Berkowitz, (2008)	12	4	English	21.9	Musical improvisation	Pattern playing	Rhythm improvisation > Pattern playing
Berkowitz, (2008)	12	4	English	21.9	Musical improvisation	Pattern playing	Pattern playing > Rhythm improvisation
de Aquino, (2019)	19	9	Spanish	20.26 ± 2.05	Musical improvisation	Melody repetition	Improvisation > Repetition
de Aquino, (2019)	19	9	Spanish	20.26 ± 2.05	Musical improvisation	Melody repetition	Repetition > Improvisation
de Aquino, (2019)	21	5	Spanish	20.19 ± 2.36	Musical improvisation	Melody repetition	Improvisation > Repetition
de Aquino, (2019)	21	5	Spanish	20.19 ± 2.36	Musical improvisation	Melody repetition	Repetition > Improvisation
de Manzano, (2012a) ^d	18	17	Swedish	39 ± 12	Musical improvisation	Random key press	Key pressing > Improvisation
de Manzano, (2012b)	15	14	Swedish	40 ± 12	Musical improvisation	Sight reading	Improvisation > Reading
de Manzano, (2012b)	15	14	Swedish	40 ± 12	Musical improvisation	Sight reading	Reading > Improvisation
Dhakal, (2019) ^c	24	24	English	21.30 ± 13.6	Musical improvisation	Melody repetition	Improvisation > Repetition
Donnay, (2014)	11	11	English	38.80 ± 11	Musical improvisation	Melody repetition	Improvisation > Repetition
Donnay, (2014)	11	11	English	38.80 ± 11	Musical improvisation	Melody repetition	Repetition > Improvisation
Limb, (2008)	6	6	English	34.20 ± 10.4	Musical improvisation	Melody repetition	Improvisation > Repetition
Limb, (2008)	6	6	English	34.20 ± 10.4	Musical improvisation	Melody repetition	Repetition > Improvisation
Liu, (2012)	12	12	English	30.3	Lyrics improvisation	Lyrics repetition	Improvisation > Repetition
Liu, (2012)	12	12	English	30.3	Lyrics improvisation	Lyrics repetition	Repetition > Improvisation
Lu, (2017)	29	14	Chinese	18–23	Unfamiliar improvisation	Familiar improvisation	Unfamiliar > Familiar
Lu, (2017)	29	14	Chinese	18–23	Unfamiliar improvisation	Familiar improvisation	Familiar > Unfamiliar
McPherson, (2016)	12	11	English	39.9 ± 15.8	Musical improvisation	Chromatic scale playing over entire range keyboard	Improvisation > Scale
McPherson, (2016)	12	11	English	39.9 ± 15.8	Musical improvisation	Chromatic scale playing over entire range keyboard	Scale > Improvisation
Villarreal, 2013 ^d	11	9	Spanish	21.9 ± 1.6	Musical creation (high creatives)	Repetition	Creation > Repetition
Villarreal, 2013 ^d	10	9	Spanish	21.9 ± 1.6	Musical creation (low creatives)	Repetition	Creation > Repetition
Visual creativity							
Asari, (2008)	68	27	Japanese	23.3 ± 3.5	Unique responses on ambiguous figures	Frequent responses on ambiguous figures	Unique > Frequent
Asari, (2008)	68	27	Japanese	23.3 ± 3.5	Unique responses on ambiguous figures	Frequent responses on ambiguous figures	Frequent > Unique
Aziz-Zadeh, (2013)	13	6	English	23.15 ± 3.36	Composite image creation	Mental rotation	Creation > Rotation
Aziz-Zadeh, (2013)	13	6	English	23.15 ± 3.36	Composite image creation	Mental rotation	Rotation > Creation
Cai, (2018) ^c	16	8	Chinese	20 ± 1.34	Object creation	Mental rotation	Creation > Rotation
Ellamil, (2012)	15	6	English	22.14 ± 2.25	Generate book covers	Evaluate book covers	Generation > Evaluation
Ellamil, (2012)	15	6	English	22.14 ± 2.25	Generate book covers	Evaluate book covers	Evaluation > Generation
Hahm, (2017) ^c	25	11	Korean	19.9 ± 1.8	Drawing	Line tracking	Drawing > Tracking
Huang, (2013)	28	13	Chinese	22	Novel image construction	Common pattern construction	Novel > Common
Huang, (2013)	28	13	Chinese	22	Novel image construction	Common pattern construction	Common > Novel
Saggar, (2015)	30	14	English	28.77 ± 5.54	Pictionary based word drawing	Zig-zag line drawing	Word > Line
Saggar, (2015)	30	14	English	28.77 ± 5.54	Pictionary based word drawing	Zig-zag line drawing	Line > Word

Note. ^a Studies using linguistic alternate use task, ^b Studies using other linguistic tasks, ^c Studies non reporting the analyses of Deactivations preceding spatial enhancement, ^d Studies reporting non-significant Deactivations preceding spatial enhancement, ^e Studies reporting non-significant Deactivations preceding spatial enhancement but no coordinates. AUT: Alternative uses Task, IT: Instances, OC: Object Characteristics. For further details (e.g., country of data collection, magnetic flux density, presence of behavioral data, contact information, stimuli task nature, threshold used for the contrast, direction of the contrast and stereotaxic coordinates of each peak of activity and its statistics) can be found here.

3.1. Meta-analysis on overall creativity

Activations. Four clusters were identified as statistically significant for the overall meta-analysis on studies associated with the overall creativity process (Fig. 2A and Table 2): the left precentral gyrus, left midcingulate cortex, right cerebellum, and left supramarginal gyrus. We found low between-study heterogeneity for each significant peak ($I^2 = 10.48 - 15.60\%$), and moderate between-study heterogeneity in the left inferior parietal gyri excluding the angular gyri ($I^2 = 56.43\%$). The funnel plots were symmetric, and the tests for potential publication bias were not statistically significant ($p = .12 - .55$), except for the peak in the middle cingulate cortex ($p = .04$). However, the Excess Significance Test (EST) demonstrated that the meta-analyses findings were highly reliable and valid overall peaks ($p = .76 - 1$).

Deactivations. Before TFCE-correction, five clusters were identified as statistically significant as deactivations (Fig. 3A and Table 2): the right angular gyrus, right precuneus, right middle frontal gyrus, and left angular gyrus. We found moderate to substantial between-study heterogeneity for each significant peak ($I^2 = 24.59 - 65.06\%$). The funnel plots were symmetric, and the tests for potential publication bias were not statistically significant in most of the peaks ($p = .39 - .91$). Even though the peaks on the right precuneus and the middle frontal gyrus revealed publication bias ($p = .04, .02$), the ETS demonstrated that the findings were highly reliable and valid overall peaks ($p = .66 - 1$). After TFCE-correction, only one cluster was significant in the right angular gyrus. We found moderate between-study heterogeneity for this peak ($I^2 = 58.17\%$). The funnel plot was symmetric, the tests for potential publication bias and ETS were not statistically significant ($p = .23, p = 1$).

3.1.1. Overall creativity excluding AUT

Activations. Three significant clusters were identified in overall creativity excluding AUT studies (Fig. 2B, Table 2): the left rolandic operculum, left middle cingulate cortex, and right cerebellum. Each peak exhibited low between-study heterogeneity ($I^2 = 4.50 - 17.66\%$) and symmetric funnel plots. The tests for potential publication bias and ETS that were not statistically significant ($p = .05 - .68; p = .48 - 1$).

Deactivations. Before TFCE-correction, seven clusters were significantly identified in overall creativity excluding AUT studies (Fig. 3B, Table 2): the right posterior cingulate cortex, two peaks in the right middle frontal gyrus, the right inferior temporal gyrus, right angular gyrus, right supramarginal gyrus, and right superior temporal gyrus. The increased number of clusters in comparison to overall creativity, suggests that AUT works as a glue to the volume of the clusters. We found low to moderate between-study heterogeneity for each significant peak ($I^2 = .78 - 33.82\%$), except for substantial heterogeneity in the peak in right angular gyrus, and the right middle frontal gyrus ($I^2 = 52.30\%, 53.82\%$). The funnel plots were symmetric, and the tests for potential publication bias were not statistically significant ($p = .07 - .90$), but the peak in the right middle frontal gyrus was ($p = .02$). The ETS demonstrated that the findings were highly reliable and valid peaks ($p = .23 - .97$), except for the peak in the right inferior temporal gyrus ($p = .0$). After correction, no statistically significant clusters were identified.

3.1.2. Linguistic creativity

Activations. Five clusters were involved in linguistic creativity (Fig. 2C, Table 2): the right cerebellum, left precentral gyrus, left anterior cingulate, left supramarginal gyrus, and right superior occipital gyrus. We found low between-study heterogeneity for each significant

peak ($I^2 = 1.34 - 12.89\%$) and moderate between-study heterogeneity of the peak in the left supramarginal gyrus ($I^2 = 63.93\%$). The funnel plots were symmetric and the tests for potential publication bias and ETS were not significant ($p = .15 - .38; p = .86 - 1$).

Deactivations. Before TFCE-correction, linguistic creativity was associated with four clusters in the right hemisphere (Fig. 3C, Table 2): the inferior parietal gyrus, two peaks in the precuneus, and right middle frontal gyrus. We found low to moderate between-study heterogeneity for each significant peak ($I^2 = 23.08 - 48.25\%$). The funnel plots were symmetric and the tests for potential publication bias and ETS were not statistically significant ($p = .10 - .38; p = .85 - 1$). After the TFCE-correction, we only found one cluster with the center in the right inferior parietal gyri (Table 2). This peak exhibited low between-study heterogeneity ($I^2 = 25.39\%$). The funnel plot was symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = .81, p = .97$).

3.1.3. AUT

Activations. Four clusters were related to AUT (Fig. 2D, Table 2): the left supramarginal gyrus, two peaks in left inferior frontal gyrus, and the right middle cingulate cortex. The cluster size was lower than the size of the other domains, indicating reduced methodological variability relative to other expressive domains. As expected, we found low between-study heterogeneity for AUT ($I^2 = 7 - 22.43\%$). The funnel plots were symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = .06 - .26, p = .4 - .9$).

Deactivations. After TFCE-correction, only one cluster remained, centered in the right angular gyrus (Fig. 3D, Table 2). This region was present in linguistic creativity before TFCE-correction and after TFCE-correction in both overall creativity and AUT, highlighting its relevance to AUT and, by expansion, to creativity. This peak exhibited low between-study heterogeneity ($I^2 = 9\%$). The funnel plot was symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = .65, p = .4$). However, no clusters were identified before TFCE-correction. The deactivations may only emerge after TFCE correction, which preserves spatial structure and enhances sensitivity to small clusters (Smith and Nichols, 2009).

3.1.4. Linguistic creativity excluding AUT

Activations. When excluding AUT from linguistic creativity, only two clusters showed statistical significance (Fig. 2E, Table 2): the right cerebellum and left triangular part of the left inferior frontal gyrus. We found low between-study heterogeneity for each peak ($I^2 = 2.40 - 7.62\%$). The funnel plots were symmetric, the tests for potential publication bias and ETS were not statistically significant ($p = .70 - .82; p = .24 - .96$).

Deactivations. Before TFCE-correction, two clusters were identified and associated with the other linguistic tasks different from AUT (Fig. 3E, Table 2): the right precuneus and right inferior parietal gyri excluding the supramarginal gyrus. We found low between-study heterogeneity for each significant peak ($I^2 = 3.16 - 9.26\%$). The funnel plots were symmetric, the tests for potential publication bias and ETS were not statistically significant ($p = .18 - .91, p = -.25 - 1$). No clusters survived after TFCE-correction.

3.1.5. Musical creativity

Activations. Four clusters were significant in the music meta-analysis (Fig. 2F, Table 2): the left supplementary motor area, two peaks centered in the left part of the opercular inferior frontal gyrus and the left inferior parietal gyri. We found low between-study heterogeneity for each

Table 2

Activations and Deactivations preceding spatial enhancement of overall creativity and specific expressive domains.

C	Anatomical region(s)	L/R	Vxls (mm ³)	Peak x y z			Z-Max
Overall creativity							
Activations							
1	Precentral gyrus	L	3793	−48	2	22	6.812
	Inferior frontal gyrus: triangular	L		−46	28	0	5.918
	Inferior frontal gyrus: opercular	L		−52	14	22	5.744
	Middle frontal gyrus	L		−46	30	30	4.524
	Inferior frontal gyrus: orbital	L		−46	22	−10	4.506
	Insula	L		−32	20	−6	3.268
2	Middle cingulate cortex	L	3216	−6	20	32	6.091
	Anterior cingulate cortex	L		−2	20	30	5.908
	Superior frontal gyrus: medial	L		−8	20	42	5.832
	Cingulum	L		6	22	26	4.668
	Middle frontal gyrus	L		−24	4	56	3.876
	Frontal aslant tract	L		−16	12	54	3.68
3	Cerebellum	R	2695	28	−86	−32	5.374
4	Supramarginal gyrus	L	392	−62	−34	34	4.567
	Inferior parietal gyri	L		−58	−32	46	3.978
Deactivations							
	Angular gyrus	R	124	52	−64	42	−3.38
Deactivations preceding spatial enhancement							
1	Angular gyrus	R	1727	52	−62	42	−3.4
	Supramarginal gyrus	R		60	−36	26	−2.394
2	Precuneus	R	479	6	−62	30	−2.471
3	Middle frontal gyrus	R	121	36	24	40	−2.945
4	Superior frontal gyrus: dorsolateral	R	54	32	56	8	−2.133
	Middle frontal gyrus	R		28	56	4	−1.99
5	Angular gyrus	L	12	−52	−62	44	−1.722
Overall creativity excluding AUT							
Activations							
1	Rolandic operculum	L	3164	−48	4	16	5.977
	Inferior frontal gyrus: triangular	L		−48	26	10	5.303
	Precentral gyrus	L		−58	10	28	4.983
	Inferior frontal gyrus: opercular	L		−58	10	24	4.933
2	Middle cingulate cortex	L	2706	−2	16	32	4.931
	Superior frontal gyrus: medial	L		−6	16	42	4.724
	Supplementary motor area	L		2	14	46	4.618
	Middle cingulate cortex	R		8	22	34	3.911
	Anterior cingulate	R		6	26	28	3.591
	Middle frontal gyrus	L		−24	6	56	3.361
	Precentral gyrus	L		−30	−4	60	2.777
	Superior frontal gyrus: dorsolateral	L		−22	−4	58	2.623
3	Cerebellum	R	2697	34	−82	−34	4.878
Deactivations preceding spatial enhancement							
1	Posterior cingulate gyrus	R	466	4	−42	24	−2.63
	Posterior cingulate gyrus	L		−2	−42	24	−2.63
	Cingulum	R		8	−42	26	2.624
	Cingulum	L		−6	−42	26	2.596
	Precuneus	R		12	−64	36	2.515
	Middle cingulate cortex	L		−2	−42	38	1.766
2	Middle frontal gyrus.	R	204	38	24	40	−3.15
3	Inferior temporal gyrus	R	116	52	−72	−4	2.518
4	Angular gyrus	R	124	44	−64	46	2.033
5	Supramarginal gyrus	R	45	58	−30	32	2.249
6	Superior temporal gyrus	R	43	60	−58	22	2.106
7	Middle frontal gyrus: orbital	R	41	10	44	−12	1.847
	Rectus gyrus	R		6	48	−16	−1.76
Linguistic creativity							
Activations							
1	Cerebellum	R	3197	28	−64	−44	5.699
	Fusiform gyrus	R		24	−62	−14	3.42
2	Precentral gyrus	L	3300	−52	2	20	5.484
	Inferior frontal gyrus: triangular	L		−52	28	2	4.858
	Inferior fronto-occipital fasciculus	L		−46	28	4	4.669
	Frontal orbito-polar tract	L		−30	28	−16	4.117
	Superior temporal gyrus	L		−48	8	−20	3.954
	Inferior frontal gyrus: orbital	L		−40	20	−10	3.85
	Inferior frontal gyrus: opercular	L		−54	10	12	3.823
	Middle temporal gyrus	L		−48	2	−22	3.807
	Insula	L		−36	20	−6	3.57
	Precentral gyrus	L		−50	4	34	2.945
3	Anterior cingulate	L	2389	0	38	22	5.817
	Anterior cingulate	R		4	38	24	5.202
	Superior frontal gyrus: dorsolateral	L		−12	24	54	5.013

(continued on next page)

Table 2 (continued)

C	Anatomical region(s)	L/R	VxIs	Peak			
4	Superior frontal gyrus: medial	L		−8	18	42	4.409
	Middle cingulate cortex	R		6	10	42	4.073
	Supplementary motor area	L		−4	22	50	3.477
	Superior frontal gyrus: medial	L		−8	38	44	2.945
	Supramarginal gyrus	L	314	−62	−30	32	4.393
	Postcentral gyrus	L		−58	−18	36	4.206
5	Supramarginal gyrus	L		−60	−30	46	3.672
	Superior occipital gyrus	R	28	20	−92	16	4.562
<i>Deactivations</i>							
	Inferior parietal gyri	R	14	50	−44	52	−3.896
<i>Deactivations preceding spatial enhancement</i>							
1	Inferior parietal gyri	R	2114	50	−44	52	−3.896
	Superior longitudinal fasciculus III	R		48	−42	36	−2.908
	Angular gyrus	R		52	−64	42	−2.77
	Supramarginal gyrus	R		60	−40	32	−2.016
2	Precuneus	R	348	14	−64	34	−2.199
	Precuneus	L		−4	−66	42	−2.095
	Precuneus: medial			0	−64	44	−2.073
3	Middle frontal gyrus	R	72	30	46	8	−2.182
4	Precuneus	R	63	18	−72	46	−2.092
<i>Alternative uses task</i>							
<i>Activations</i>							
1	Supramarginal gyrus	L	823	−60	−22	40	4.942
	Inferior parietal gyri	L		−58	−24	44	4.872
	Postcentral gyrus	L		−58	−18	30	4.638
2	Inferior frontal gyrus: opercular	L	137	−50	8	28	4.172
	Precentral gyrus	L		−54	4	20	3.802
3	Middle cingulate cortex	R	47	2	22	38	4.089
	Middle cingulate cortex	L		−6	20	34	3.985
	Superior frontal gyrus: medial	L		−6	20	40	3.894
4	Inferior frontal gyrus: orbital	L	22	−34	28	−16	4.497
	Uncinate fasciculus	L		−34	28	−12	4.107
<i>Deactivations</i>							
1	Angular gyrus	R	1662	50	−64	46	−5.525
	Inferior parietal gyri	R		48	−46	50	−4.913
	Supramarginal gyrus	R		52	−44	34	−4.225
	Superior occipital gyrus	R		30	−74	44	−3.252
<i>Linguistic creativity excluding alternate uses task</i>							
<i>Activations</i>							
1	Cerebellum	R	3434	18	−66	−42	5.915
	Lingual gyrus	R		22	−72	−14	3.111
2	Inferior frontal gyrus: triangular	L	957	−56	24	14	4.527
	Inferior frontal gyrus: opercular	L		−50	8	8	4.371
	Superior longitudinal fasciculus III	L		−46	24	12	4.168
	Inferior frontal gyrus: opercular	L		−44	18	12	4.024
	Precentral gyrus	L		−60	6	22	3.522
	Frontal aslant tract	L		−48	2	20	3.397
<i>Deactivations preceding spatial enhancement</i>							
1	Precuneus	R	90	14	−64	34	−2.607
	Precuneus	R		8	−62	46	−1.963
2	Inferior parietal	R	74	52	−48	54	−2.121
	Supramarginal gyrus	R		42	−38	44	−1.954
	Middle occipital gyrus	R		32	−72	40	−3.116
<i>Musical creativity</i>							
<i>Activations</i>							
1	Supplementary motor area	L	3191	2	16	48	5.807
	Supplementary motor area	R		4	10	54	5.545
	Middle frontal gyrus	L		−26	−6	50	4.835
	Middle cingulate cortex	L		0	16	36	4.294
	Superior frontal gyrus	L		−14	14	56	3.952
	Superior frontal gyrus: medial	L		−4	32	36	3.152
2	Inferior frontal gyrus: opercular	L	1585	−52	12	24	6.131
	Precentral gyrus	L		−50	8	32	5.425
	Inferior frontal gyrus: triangular	L		−50	30	10	3.815
3	Inferior frontal gyrus: opercular	R	195	54	16	10	4.346
4	Inferior parietal gyri	L	17	−44	−36	46	4.385
<i>Deactivations</i>							
	Angular gyrus	L	8	−46	−60	24	−3.745
<i>Deactivations preceding spatial enhancement</i>							
1	Optic radiations	L	969	−22	−32	−6	−3.144
	Hippocampus	L		−26	−30	−8	−3.006
	Parahippocampal gyrus	L		−30	−44	−8	−3.004
	Lingual gyrus	L		−30	−38	−8	−2.984
	Cingulum	L		−26	−30	−14	−2.966
	Inferior longitudinal fasciculus	L		−36	−34	−18	−2.876
	Fusiform gyrus	L		−28	−42	−12	−2.586

(continued on next page)

Table 2 (continued)

C	Anatomical region(s)	L/R	Vxls	Peak			
2	Hippocampus	R	684	30	−16	−16	−3.362
	Inferior longitudinal fasciculus	R		32	32	−18	−2.88
	Parahippocampal gyrus	R		30	−28	−14	−2.705
	Fusiform gyrus	R		28	−46	−12	−2.602
3	Angular gyrus	L	491	−46	−60	24	−3.745
	Middle temporal gyrus	L		−40	−58	20	−3.09
4	Cingulum	R	469	10	−46	30	−2.62
	Posterior cingulate gyrus			0	−46	20	−2.399
	Posterior cingulate gyrus	L		−6	−48	32	−1.69
	Cingulum	L		−6	−40	26	−2.067
	Precuneus	R		4	−52	44	−1.891
5	Angular gyrus	R	357	56	−58	26	−2.909
	Inferior parietal gyri	R		56	−54	44	−2.417
	Supramarginal gyri	R		64	−46	38	−2.033
6	Inferior temporal gyrus	R	299	52	−70	−6	−2.789
	Inferior longitudinal fasciculus	R		42	−68	6	−2.382
7	Middle frontal gyrus	R	250	36	24	36	−2.831
8	Middle frontal gyrus	L	186	−40	24	50	−2.945
9	Precuneus	L	66	−6	−64	50	−1.881
10	Paracentral lobule	R	55	4	−28	68	−2.258
11	Paracentral lobule	L	33	−14	−26	66	−2.078
12	Cingulum	L	13	−10	−50	26	−1.814
	Posterior cingulate gyrus	L		−12	−50	30	−1.709
<i>Visual creativity</i>							
<i>Activations preceding spatial enhancement</i>							
1	Middle occipital gyrus	L	1413	−28	−74	36	3.54
	Superior parietal gyrus	L		−14	−64	48	2.581
	Precuneus	L		−8	−72	54	2.197
2	Superior frontal gyrus: dorsolateral	R	549	32	−6	58	3.333
	Middle frontal gyrus	R		34	4	52	1.972
3	Inferior frontal gyrus: opercular	L	394	−48	10	26	3.296
	Precentral gyrus	L		−50	2	22	2.1
4	Precentral gyrus	L	375	−32	−8	52	2.647
	Superior frontal gyrus	L		−24	−2	48	2.53
	Superior frontal gyrus: dorsolateral	L		−26	−10	60	1.842
5	Superior frontal gyrus: medial	R	267	6	20	44	1.998
	Supplementary motor area	L		0	22	44	1.796
	Cingulum	L		−10	20	40	1.779
	Middle cingulate cortex	R		6	10	38	1.71
	Supplementary motor area	L		2	14	44	1.707
6	Inferior frontal gyrus: triangular	L	215	−50	32	8	2.529
7	Fusiform gyrus	L	211	−44	−50	−22	2.067
	Inferior temporal gyrus	L		−50	−52	−18	1.9
	Cerebellum	L		−32	−32	−32	1.861
	Inferior temporal gyrus	L		−42	−50	−12	1.795
8	Inferior frontal gyrus: opercular	R	117	50	8	14	2.155
9	Precuneus	R	61	8	−62	54	2.153
	Superior parietal gyrus	R		22	−68	48	1.858
10	Cerebellum	L	59	−6	−60	−42	1.971
11	Inferior frontal gyrus: orbital	L	40	−38	24	−12	1.888
12	Gyrus rectus	L	36	−10	22	−20	2.171
<i>Deactivations preceding spatial enhancement</i>							
1	Inferior longitudinal fasciculus	L	297	−22	−92	−10	−2.54
	Middle occipital gyrus	L		−30	−94	−6	−2.32
	Lingual gyrus	L		−22	−92	−14	−2.214
	Fusiform gyrus	L		−34	−78	−18	−2.181
2	Inferior occipital gyrus	R	167	32	−86	−8	−2.62

Note. C = clusters. L/R= left/right. Vxls = voxels size. Z-Max: maximum effect-size identified for the anatomical region within the cluster. AUT = Alternate Uses Task. Activations were FWE-corrected ($p < .05$), TFCE-corrected ($p < .05$) and voxel extent ≥ 10 . Activations preceding spatial enhancement were FWE-corrected, ($p < .05$) TFCE-uncorrected ($p < .05$), and voxel extent ≥ 10 . Deactivations preceding spatial enhancement were FWE-corrected ($p < .05$). Deactivations were FWE-corrected, ($p < .05$) TFCE-uncorrected ($p < .05$) and voxel extent ≥ 10 . Only the coordinates associated with the maximum peak of the brain region within the cluster are displayed. Further peaks and coordinates within the cluster can be accessed in the supplementary material. Detailed information regarding the brain regions ' and their voxel size ($2 \times 2 \times 2$ mm voxel size) contribution to each cluster can be accessed [here](#).

significant peak ($I^2 = .73 - 7.48$ %). The funnel plots were symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = .11 - .46$, $p = .40 - .98$).

Deactivations. The meta-analysis of musical creativity revealed fourteen clusters that showed statistical significance when uncorrected (Fig. 3F, Table 2): the left optic radiations, right hippocampus, right and left angular gyrus, right cingulum, right inferior temporal gyrus, right and left middle frontal gyrus, left precuneus, right and left paracentral lobule, and left cingulum. We found low between-study heterogeneity

for each significant peak ($I^2 = 1.69 - 64.78$ %). The funnel plots were symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = -3.61 - -0.46$; 0 - 1). After TFCE-correction, only one cluster in the left angular gyrus including the inferior parietal gyri showed significance (Table 2). This peak exhibited low between-study heterogeneity ($I^2 = 23.14$ %). The funnel plot was symmetric, and the tests for potential publication bias and ETS were statistically significant ($p = .02$, $p = .83$).

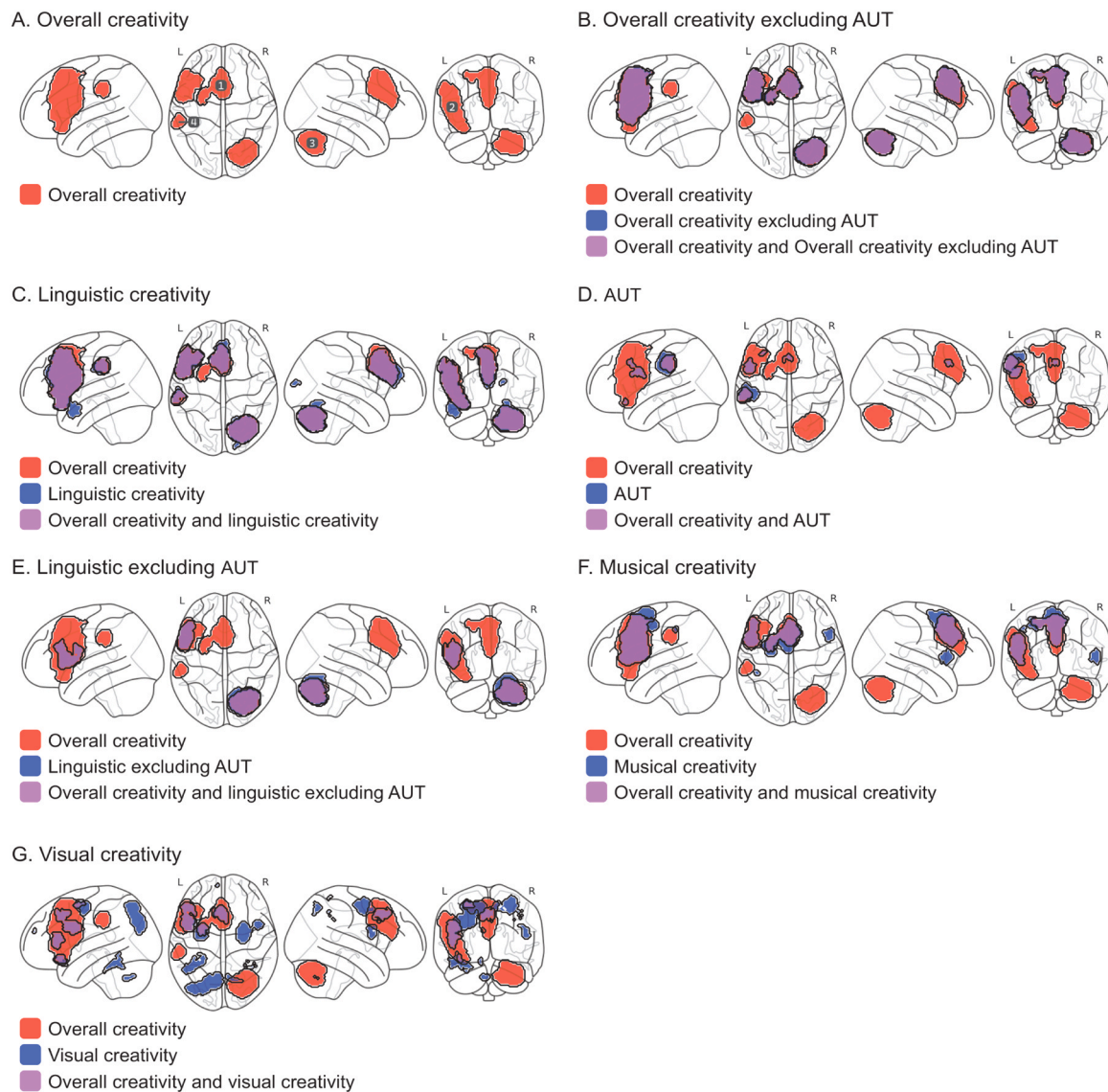


Fig. 2. Activations of overall creativity meta-analysis and the contribution of the sub meta-analyses. A. Overall creativity: peaks: 1. Left precentral gyrus, including left: inferior frontal gyrus (opercular, triangular, orbital), middle frontal gyrus, insula. 2. Left middle cingulate, including the left: anterior cingulate, frontal aslant tract, middle frontal gyrus, bilateral superior frontal gyrus. 3. Right cerebellum. 4. Left supramarginal gyrus including the left inferior parietal gyri excluding angular gyrus. B. Overall Creativity excluding AUT. C. Linguistic creativity. D. Linguistic creativity excluding AUT. E. AUT. F. Musical creativity. G. Visual Creativity. The extent of the uniqueness of the activations within the expressive domains is illustrated in Fig. 4. A-F. Images were FWE-corrected ($p < .05$), TFCE-corrected ($p < .05$), voxel extent < 10 . G. Visual creativity is FWE-corrected ($p < .05$), TFCE-uncorrected ($p < .05$), voxel extent < 10 . AUT = Alternative Uses Task.

3.1.6. Visual creativity

Activations. Twelve clusters associated with the visual expressive domain were detected but none was exhibited after TFCE-correction (Fig. 2G, Table 2): the left middle occipital gyrus, two peaks in the superior frontal gyrus, three peaks in the left inferior frontal gyrus, the left precentral gyrus, left fusiform gyrus, right precuneus, left cerebellum, and left gyrus rectus. We found low between-study heterogeneity for each significant peak ($I^2 = 3.16 - 23.27\%$). The funnel plots were symmetric, and the tests for potential publication bias and ETS were not statistically significant ($p = .16 - .90$; $p = .52 - 1$).

Deactivations. Two clusters (Fig. 3G, Table 2) were found: the left inferior longitudinal fasciculus and right inferior occipital gyrus; and had low between-study heterogeneity ($I^2 = 6.78 - 17.28\%$). The funnel plots were symmetric, the tests for potential publication bias and ETS were not statistically significant ($p = .57 - .81$; $p = .53 - .55$).

3.2. Uniqueness of sub meta-analyses

Fig. 4A and Fig. 4B exhibit the unique activations and deactivations of each sub meta-analysis, respectively.

Activations. As visualized in Fig. 4A, the left inferior and middle frontal gyri and the rolandic operculum were associated with visual and musical creativity, but without overlapping neuronal populations within these regions. Linguistic creativity showed unique activations in the left middle temporal gyrus, right fusiform gyrus, and right lingual and superior occipital gyri. Particularly, for AUT, the left inferior parietal gyrus, including the supramarginal and postcentral gyri, persists after controlling for overall creativity. Visual creativity showed distinct activation in the bilateral fusiform gyrus, occipital cortex, bilateral superior frontal gyri, left inferior parietal cortex, right precentral gyrus, and bilateral superior parietal gyri. Further conjunction analyses between the uniqueness of the sub meta-analyses showed that visual creativity shared activations with linguistic and musical creativity in the

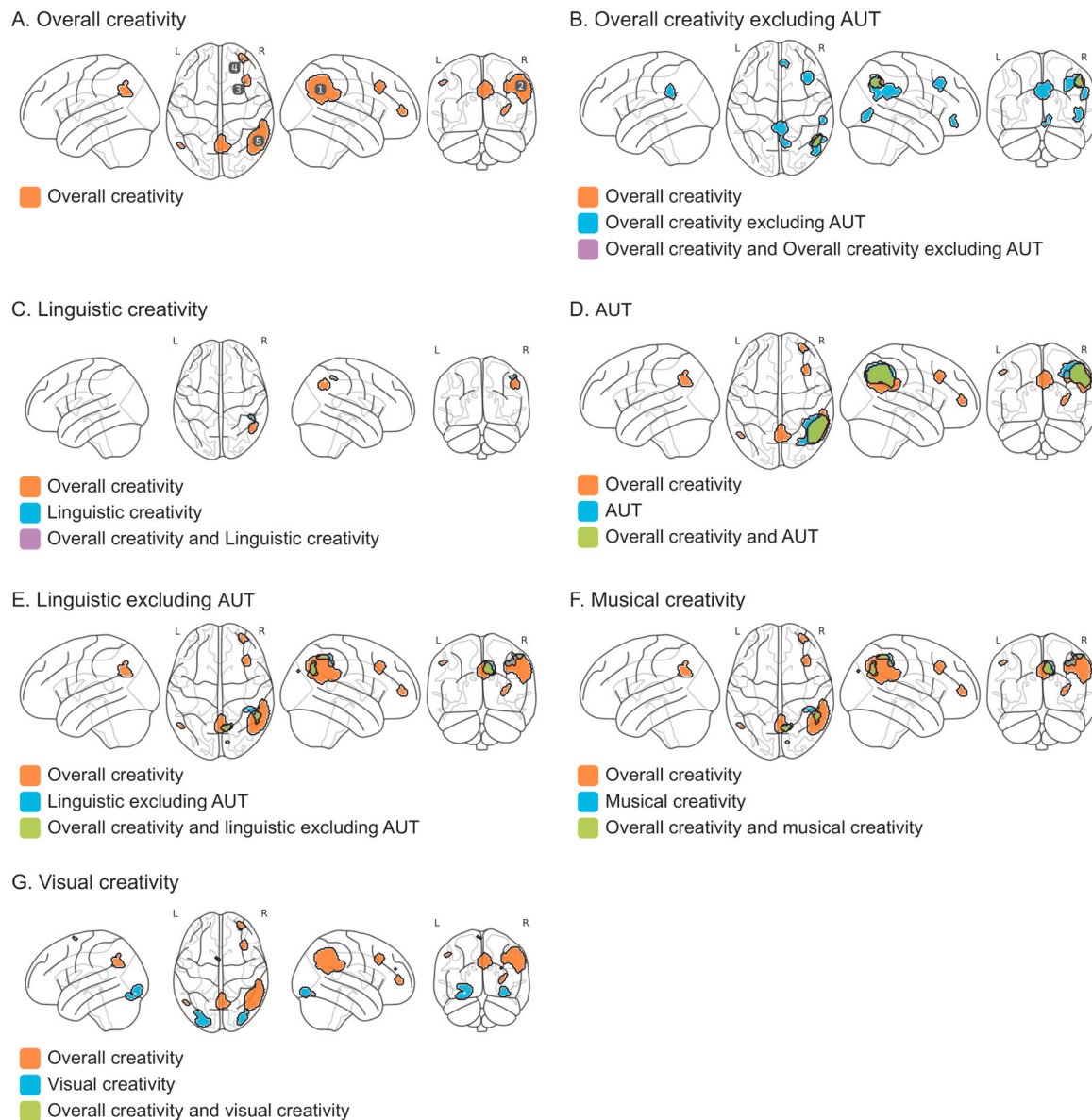


Fig. 3. Deactivations of overall creativity meta-analysis and the contribution of the sub meta-analysis. A. Overall creativity. 1. Right angular gyrus, including the right: supramarginal gyrus, middle and superior temporal gyrus. 2. Right precuneus including the bilateral posterior cingulate cortex and the right middle cingulate cortex. 3. frontal aslant tract, superior and middle frontal gyrus. 4. Left angular gyrus. B. Overall creativity excluding AUT. C. Linguistic creativity. D. Linguistic creativity excluding Alternative uses task. E. AUT. F. Musical creativity. G. Visual creativity. A–F. Images were FWE-corrected ($p < .05$), voxel extent < 10 . E. AUT is FWE-corrected ($p < .05$), TFCE-corrected ($p < .05$), voxel extent < 10 . AUT = Alternative Uses Task.

left precentral and left superior and middle frontal gyri. However, these activations did not overlap for linguistic and musical creativity, suggesting the recruitment of specialized neural populations within the same region.

Deactivations. As illustrated in Fig. 4B, clusters in the right inferior parietal gyrus across linguistic tasks showed uniqueness after subtracting the activity associated with overall creativity. The bilateral precuneus showed deactivation during musical and non-AUT linguistic tasks, but not in AUT. Further conjunction in the uniqueness of the sub meta-analyses exhibited that the deactivations linked to linguistic creativity in the inferior part of the parietal gyri and the supramarginal gyrus were shared with both AUT and the other linguistic tasks. After controlling for overall creativity, linguistic creativity shared deactivations with linguistic tasks different to AUT, in the right precuneus, the postcentral gyrus, and the superior parietal gyrus. The linguistic domain shared with AUT the right angular gyrus. Additionally, overall

creativity, excluding AUT shared deactivations in the right precuneus, is particularly driven by deactivation in linguistic tasks other than AUT.

3.3. Voxel contribution analysis

Table 3 shows each domain's contribution to overall creativity, with and without AUT. Fig. 2 visually represents these contributions. As expected, overall creativity excluding AUT closely resembled overall creativity, as evidenced by both the percentage of contributing voxels and a high degree of similarity. In line with the number of studies included, domain contributions increased in the following order: visual $<$ musical $<$ linguistic. Surprisingly, the AUT showed the lowest contribution among all domains, despite exceeding the number of included articles for the other linguistic tasks, as well as for the musical and visual domains. Regarding deactivations, overall creativity excluding AUT was the sub meta-analysis that shared the most similarity

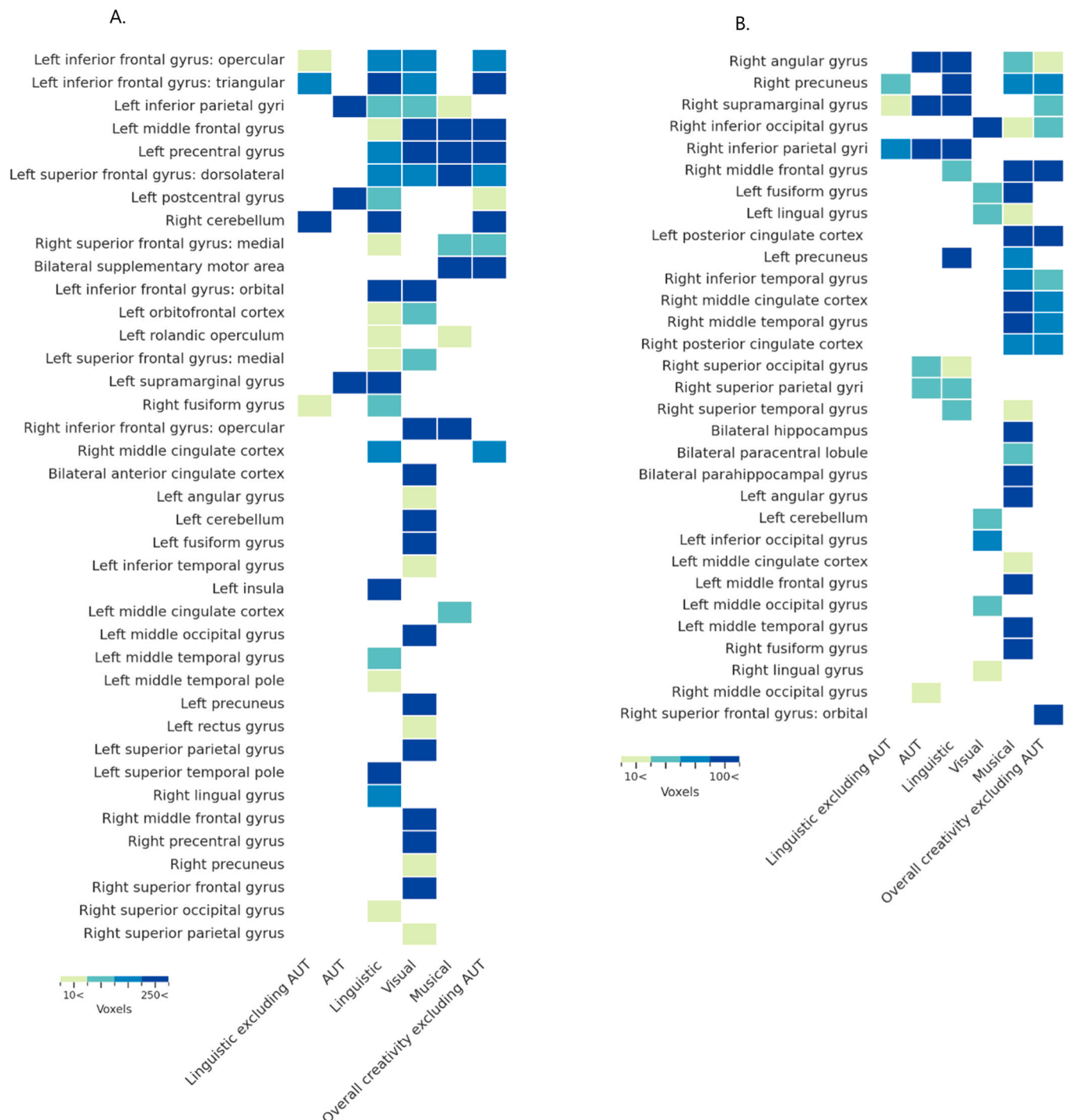


Fig. 4. Uniqueness of the activations and deactivations of the sub meta-analyses. A. Activations. FWE-corrected, TFCE-corrected, and voxel extent > 10 brain maps of overall creativity and all the sub meta-analyses, except for the visual sub-meta-analysis (FWE-corrected, TFCE-uncorrected and voxel extent > 10). Results did not differ when examining the uniqueness of the activations of the visual domain with respect to overall creativity after using the same correction thresholds as the visual sub meta-analysis. B. Deactivations. Unique deactivations were identified considering the FWE-corrected and voxel extent > 10 brain maps of overall creativity and all the domains, except for AUT sub meta-analyses (FWE-corrected, TFCE-corrected and voxel extent > 10). The AUT results remained the same when using the overall creativity brain map with the same correction thresholds, suggesting a strong contribution of AUT to overall creativity. Further details regarding cluster size and coordinates of the conjunction analyses are available in the project repository. AUT: Alternative uses task.

with overall creativity, followed by the linguistic domain, and musical creativity. No deactivation contribution was detected for the visual domain. Other linguistic creative tasks contributed less to the deactivation pattern than AUT. The same patterns observed in overall creativity were consistent with those found in overall creativity excluding AUT.

4. Discussion

The present voxel-based meta-analysis aims to systematically investigate the brain activity maps associated with overall creativity and within the expressive domains of linguistic, musical, and visual creativity. We found no overlap between activations and deactivations in

Table 3
Contribution analyses of the sub meta-analyses to overall creativity.

Sub meta-analyses	Shared Voxels (mm ³)	Contribution (%)	Dice Coefficient (%)
<i>Activations of overall creativity</i>			
Overall creativity excluding AUT	8101	80.24	89.04
Linguistic	7771	76.97	86.99
AUT	535	5.30	10.06
Linguistic excluding AUT	3229	31.98	48.47
Musical	3536	35.02	51.88
Visual	971	9.62	17.55
<i>Deactivations preceding spatial enhancement of overall creativity</i>			
Overall creativity excluding AUT	433	18.09	30.64
Linguistic	1679	70.16	82.47
AUT	124	5.18	9.85
Linguistic excluding AUT	76	3.18	6.16
Musical	551	23.03	37.43
Visual	0	0.00	0.00
<i>Activations of overall creativity excluding AUT</i>			
Linguistic	6605	77.10	87.07
AUT	184	2.15	4.21
Linguistic excluding AUT	3364	39.27	56.39
Musical	3506	40.92	58.08
Visual	949	11.08	19.95
<i>Deactivations preceding spatial enhancement of overall creativity excluding AUT</i>			
Linguistic	246	23.68	38.29
AUT	124	11.93	21.32
Linguistic excluding AUT	45	4.33	8.30
Musical	607	58.42	73.75
Visual	0	0.00	0.00

Note. This analysis was based on overlapping brain maps between each sub meta-analysis and overall creativity (or overall creativity excluding AUT). All activation maps were FWE-corrected ($p < .05$), TFCE-corrected ($p < .05$), with a voxel extent threshold of ≥ 10 , except for visual creativity, which was FWE-corrected ($p < .05$), TFCE-uncorrected ($p < .05$), with the same voxel extent. Deactivations preceding spatial enhancement maps were FWE-corrected ($p < .05$), except for AUT, which used FWE-corrected ($p < .05$), TFCE-corrected ($p < .05$) thresholds. AUT = Alternative Uses Task.

overall creativity or within the expressive domains, suggesting a functional dissociation between regions that support creative engagement and those that are downregulated during creative cognition (Beatty et al., 2016; Liu et al., 2020). Activations across all domains suggested domain-general mechanisms. Deactivations were primarily driven by linguistic and musical creativity, suggesting domain-specific mechanisms underlying visual creativity in relation to deactivation patterns. However, this result may also be attributed to the smaller number of studies reporting deactivations within the visual domain.

4.1. Neural activations associated with creativity

Our results support other meta-analyses (Gonen-Yaacovi, 2013; Brown and Kim, 2021; Boccia et al., 2015) which found an increase of activity in both right and left hemispheres associated with creativity. However, our results suggest stronger activations in the left versus right hemisphere. In previous studies, the inferior and middle frontal gyrus and the rolandic operculum exhibited bilateral activations predominantly in the left. Our results showed that this activity is restricted to the left hemisphere in overall creativity and linguistic creativity and is predominant in this left hemisphere across all expressive domains. The activations of these regions were only expanded to the right hemisphere in visual and musical creativity, however distinctive groups of cells were recruited for each expressive domain within the same region. The expansion of this activation in visual creativity is likely related to

visuospatial imagination, for instance when planning a visual artwork (De Pisapia et al., 2016). In musical creativity, it is likely related to complex musical syntax processing (Cheung et al., 2018), and increased sensitivity to pitch and tone (Hyde et al., 2006; Palomar-García et al., 2020).

Regarding the activation of the precentral gyrus, our results go against Gonen-Yaacovi et al. (2013), who reported bilateral activation, and instead align with Brown and Kim (2021) and Boccia et al. (2015), who found this activation to be restricted to the left hemisphere. Additionally, the anterior and middle cingulate cortex showed bilateral activation, with a predominance in the left hemisphere, consistent with findings from previous meta-analyses (Boccia et al., 2015; Gonen-Yaacovi et al., 2013). Likewise, we observed activations of the DMN in the bilateral superior frontal gyrus, left temporal pole, and left cingulum. All these regions have been suggested to reflect domain-general mechanisms (Brown and Kim, 2016), while other nodes of the DMN such as the left inferior parietal gyri have been considered as more sensorimotor regions, and thus domain specific (Dietrich and Kanso, 2010; Brown and Kim, 2021). The assumptions regarding the left inferior parietal gyri contradict what we observed, which is that this region – including the left supramarginal gyrus and excluding the angular gyrus – is significantly activated in overall creativity and in all expressive domains, indicating a domain-general mechanism.

Moreover, we found that motor-related regions such as the bilateral supplementary motor area (SMA) and the frontal aslant tract, previously suggested to be domain-specific (Brown and Kim, 2021), are active across general, linguistic, visual, and musical creativity. The SMA has been associated with the coordination of left and right hemispheres for motor initiation (Hertrich et al., 2016), supporting motoric mental simulations that are crucial for creative processes. This suggests that creative outputs partly rely on internally generated simulations of possible actions, which may be partially implemented within motor regions themselves (Matheson et al., 2020), either via proprioceptive mechanisms (Naito et al., 2002) or through the suppression of externally cued movements (Spiech et al., 2025). The activations observed in the frontal aslant tract, which connects the SMA with the superior and inferior frontal gyri (La Corte et al., 2021; Catani et al., 2012), likely suggest facilitation of the integration of motor simulations with executive functions during creative thought.

Other motor areas, except the supplementary motor area, showed either lateralized activation or no activation, depending on the domain. Right cerebellar activation during linguistic creativity aligns with previous findings (e.g., Boccia et al., 2015; Wu et al., 2015) and likely reflects motor involvement in language (Zhang et al., 2023). In contrast, left cerebellar activation was linked to visual creativity, consistent with Sacheli et al. (2022). Our results support Zhang et al. (2023) call to investigate cerebellar lateralization in visuospatial processing and suggest left-lateralized cerebellar involvement in creative tasks. Notably, no cerebellar activation or deactivation were observed during musical creativity, possibly due to the continuous motor demands shared by both musical improvisation and repetition.

Furthermore, linguistic creativity showed unique activations in regions tied to metaphor processing (left middle temporal gyrus), abstract symbol recognition (right fusiform gyrus), and mental scene-building in narrative construction (right lingual and superior occipital gyri). Consistent with previous findings (Chen et al., 2020), we observed in the visual domain distinct activation in the bilateral fusiform gyrus—linked to color, shape recognition, and visual imagery—and in areas associated with visuospatial processing, including the occipital cortex, bilateral superior frontal gyri, left inferior parietal cortex, right precentral gyrus, and bilateral superior parietal gyri.

In summary, activations within the ECN and DMN support the deliberate and novel assembly of basic elements, while motor simulation contributes to visualizing the forms in which the creative ideas will be expressed. Our research confirms domain-general mechanisms including the regions associated with the ECN and DMN networks

(Brown and Kim, 2021) and adds the role of brain areas associated with motor simulations as a domain-general mechanism. These mechanisms appear to support overall creativity as well as creativity across all expressive domains. Furthermore, domain-specific mechanisms seem to involve not only sensory processing (e.g., recognition of simple forms, musical syntax processing), but also the integration of these processes with higher-order cognitive functions (e.g., mental scene-building in narrative construction, visuospatial imagination).

4.2. Neural deactivations associated with creativity

Extant research associates the deactivations of both right and left angular gyrus with goal-oriented tasks attributable to the interruption of task-free semantic and conceptual processes. Such interruption results from manipulating knowledge about the world (Seghier et al., 2010). Deactivations of the angular gyrus have been associated with increased task difficulty, regardless of the semantic or non-semantic nature of the task at hand (Gilbert et al., 2012; Kuhnke et al., 2023). Our results align with this previous research as we found deactivations in the angular gyrus driven by linguistic and musical creativity and associated with highly creative tasks which are more difficult than low-creative ones, as evidenced by longer reaction times (Benedek et al., 2014b).

Fink et al. (2009a) found that lateralized activity in the parietal gyrus corresponds to a diffuse and widespread pattern of alpha synchronization in bilateral parietal regions during AUT. Consistent with this, von Stein and Sarnthein (2000) reported that long-range frontoparietal interactions during mental imagery are particularly reflected in the alpha frequency range. The pronounced alpha synchronization in the posterior parietal cortex during the generation of novel ideas may indicate that the underlying cortical networks are in a state of "internal attention" (Knyazev et al., 2006, 2007), or engaged in internal top-down processing (von Stein and Sarnthein, 2000), with reduced susceptibility to external cognitive interference (Sauseng et al., 2005) and potentially associated with high interoceptive focus (Balconi and Angioletti, 2023).

Alongside comparatively weak fMRI activation in right posterior parietal cortical regions, this widespread alpha synchronization may facilitate the (re)combination of distantly related semantic information (Jung-Beeman, 2005). de Munck et al. (2007) and Bowman (2017) empirically confirmed the correlation between alpha asymmetry and reduced fMRI activation that Fink et al. (2009b) speculated, particularly in the posterior parietal cortex. More recently, Ma et al. (2024) demonstrated that alpha-frequency stimulation of the angular gyrus, especially in the right hemisphere, causally modulates alpha rhythms within the DMN. Therefore, the deactivation of the right angular gyrus during highly linguistic creative tasks such as AUT, may reflect internally directed, top-down, interoceptive cognitive states that rely more on alpha-mediated integration across distributed parietal networks, enabling the flexible recombination of remote associations essential for creative ideation.

Our findings revealed a lateralization effect in the inferior parietal gyri for linguistic and musical creativity. The deactivation clusters observed in the right inferior parietal gyrus across linguistic tasks contribute broadly to the deactivation of creativity, which expands beyond its overlap with overall creativity. Even when excluding AUT from the overall creativity analysis, the right inferior parietal gyrus, including both the supramarginal and angular gyri, showed significant involvement. Therefore, the deactivation in this region is likely not task-specific but generalizable across linguistic contexts. Notably, the deactivation of the right angular gyrus appears to be more pronounced in AUT tasks, suggesting strong participation in linguistic ideation processes.

While AUT showed deactivation in the right angular gyrus, musical creativity was associated with stronger deactivation in the left angular gyrus. Only two studies showed the opposite pattern, likely due to their stronger linguistic components (namely, lyrics improvisation in Liu et al., 2012; and melody improvisation in Berkowitz and Ansari, 2008).

These findings support Donnay et al. (2014) interpretation that left angular gyrus deactivation reflects reduced reliance on semantic processing during musical improvisation. Given the left angular gyrus's stronger link to language semantics (Kuhnke et al., 2023; Humphreys et al., 2015, 2021), its deactivation suggests that musical meaning diverges from linguistic meaning, which is more precise and referential (Cross and Morley, 2009; Donnay et al., 2014). This challenges theories that equate music with language-like semantic processing (Koelsch et al., 2004). Instead, musical improvisation may rely more on acoustic and rhythmic processing, supported by activation in areas like the supplementary motor area (Binder et al., 1999; Spiech et al., 2025). Our findings call for a broader and more flexible framework for understanding musical semantics.

Moreover, the bilateral precuneus, which is part of the DMN, showed deactivation during musical and non-AUT linguistic tasks, suggesting a role in elaborative rather than ideational creativity. Right precuneus deactivation may reflect reduced self-referential processing (Cavanna and Trimble, 2006; Raichle, 2015) in favor of externally focused attention, supporting functions like auditory-motor integration (Beaty et al., 2016) and narrative construction (Mar, 2011). Its lack of deactivation during AUT suggests this shift is less necessary for ideation alone. Unique deactivations during musical creativity were observed in the bilateral hippocampus, parahippocampal gyrus, lingual gyrus, and cingulum – regions linked to memory retrieval, scene construction, and cognitive control. Their deactivation may support the spontaneous and embodied nature of musical improvisation by reducing interference from self-referential and memory-based processes. This aligns with the lack of cerebellar activation and highlights a shift toward fluid, real-time auditory-motor generation over structured coordination. These findings reinforce the view of musical creativity as emotionally driven and sensorimotor based (Palhares et al., 2024; Sovansky et al., 2016; Wöllner, 2024).

In the visual domain, deactivations may reflect control task demands—for example, fusiform and middle occipital activation during low-creative tasks may result from reading notation or visual tracking, rather than creative suppression. In contrast, highly creative tasks may disengage these perceptual systems to support abstract mental imagery (Chen et al., 2019; Frith et al., 2022).

4.3. Rethinking AUT: neural overlap, domain-general processes, and conceptual limits

Our findings contribute to the neuroscience literature by suggesting that AUT is a purely ideational task that belongs to our understanding of creativity. While Brown and Kim (2021) highlighted the ideational strength of a task, they separated the activations associated with this task from the other cognitive domains and reported no overlapping. In contrast, we found regional overlapping for AUT with overall creativity, even when excluding AUT, suggesting that the cognitive processes involved in this task contribute to a certain extent to overall creativity.

AUT engages domain-general creativity mechanisms, consistent with prior meta-analyses (notably, Boccia et al., 2015; Cogdell-Brooke et al., 2020; Gonen-Yaacovi et al., 2013; Wu et al., 2015). We observed activations in left-hemisphere regions like the inferior frontal gyrus and medial superior frontal gyrus, alongside deactivations in domain-general areas such as the right angular gyrus, which is a key DMN node. Notably, AUT deactivation pattern overlapped with overall creativity even when excluding AUT, underscoring shared domain-general processes and highlighting the role of deactivations in understanding creativity. Yet, deactivations are often overlooked.

Activations during AUT were strongest in the left inferior parietal gyrus, including the supramarginal and postcentral gyri, consistent with findings from other creativity tasks involving motor simulation. This cluster appears more robustly engaged in AUT than in other domains, likely due to its focus on imagining the use of manipulable objects (Ladas et al., 2024; Orban and Caruana, 2014). The enhancement of

sensorimotor areas reflects visual and motor imagery, especially for tool use. Additional activations in the left opercular and orbital inferior frontal gyrus, cingulate regions, and the uncinate fasciculus indicate integration of multiple processes: generating associative and episodic content (“What could this object remind me of?”); inhibiting typical uses (“What typical use should I ignore?”); evaluating novelty and context (“How could I use the object in a certain time/place/situation?”); and simulating tool use (e.g., “How could my or others’ motor commands lead to the use of this object?”).

AUT methodological issues, cultural sensitivity, and its emphasis on quantity over quality have cast doubt on the validity of AUT as a measure of creativity (Hocevar, 1989; Ivancovsky et al., 2021; Ogurlu et al., 2023; Silvia et al., 2008). Despite these concerns, our findings show that AUT consistently engages core neural mechanisms of creative thinking. However, its focus on tool manipulation and ideation limits its ability to capture more elaborative creative processes. Our assessment of heterogeneity, bias, and measurement validity supports the robustness of AUT activation map, though reliability remains a concern given the clustering of studies in a few labs (Brown and Kim, 2021). Notably, the lack of activation in regions like the cerebellum, insula, and fusiform gyrus – also absent in Ma and Ma (2024) – and the lack of deactivation of the bilateral precuneus suggest that AUT places lower demands on interoception and complex integration compared to other linguistic tasks (Kozioł et al., 2014; Craig et al., 2002). While effective for assessing ideation, AUT may miss key creative skills such as synthesis, originality, and critical evaluation. Such skills are essential in more complex creative work, including for instance writing a sensational fantasy novel or directing a futuristic sci-fi movie with jaw-dropping plot twists.

4.4. Limitations of the research

Several limitations of the current research should be noted. First, only 60 % of the included studies reported deactivations. Our findings underscore the importance of deactivation data for understanding the neural basis of creativity, including domain-specific and domain-general mechanisms. Although SDM enabled meaningful insights despite limited data, more consistent reporting is essential to improve generalizability and replicability. Second, as in most fMRI meta-analyses, our study used peak coordinates reported in the literature rather than raw fMRI data, which may reduce spatial precision (Radua et al., 2012; Alegria et al., 2016) and overlook temporal brain dynamics. Future research should integrate spatiotemporal information within frameworks like SDM.

Third, this meta-analysis focused on individual, cross-sectional studies of healthy participants, overlooking real-world, collaborative, and long-term creative processes (Paulus et al., 2018; Reiter-Palmon et al., 2024; Hadida et al., 2015). For example, Fink et al. (2010) found that sharing ideas during AUT enhanced creativity, highlighting the importance of external input. Despite these limitations, our meta-analysis provides a comprehensive neural map of creativity and offers a solid foundation for future research on social, longitudinal, and clinical dimensions.

4.5. Future research directions

Future research could explore how interactions with generative artificial intelligence (AI) affect creativity. While AI shows creative potential (e.g., outperforming humans on tasks like AUT; Hubert et al., 2024), it lacks creative achievement involving agency and context. AI may enhance rationality and suppress clichés (Đula et al., 2023), but overreliance on its algorithms could reduce cognitive engagement and flexibility (Passi and Vorvoreanu, 2022). Current models also lack integration of motor, emotional, and interoceptive cues – all key elements of human creativity – highlighting areas for future development.

Another suggestion involves the integration of AI to inform future research on the neural foundations of creativity by identifying underexplored domains and guiding methodological refinement. AI could

guide future creativity research by identifying underexplored areas, such as visual creativity, and improving methodological consistency. While linguistic creativity is well-studied, AI could help standardize protocols and control conditions for less examined domains. Our findings also support the use of real-time fMRI neurofeedback (Watanabe et al., 2017), with AI decoding brain states to adapt feedback in closed-loop systems. This approach could target domain-general mechanisms (e.g., DMN patterns) or domain-specific ones (e.g., left fusiform gyrus), allowing researchers to assess whether training in one enhances the other. Integrating AI and neurofeedback may also advance cross-domain research and improve experimental design.

5. Conclusion

The present SDM meta-analysis provides a comprehensive functional neuroanatomical map of creativity. By integrating SDM methodology with contribution and uniqueness analyses, we identified brain activation patterns supporting domain-general and domain-specific mechanisms. Domain-general processes involve the executive control and default mode networks, along with motor simulation regions that support idea visualization across all expressive domains. Domain-specific mechanisms, by contrast, recruit sensory and higher-order integrative processes tailored to each domain. Deactivation patterns also informed shared processes between musical and linguistic creativity and domain-specific mechanisms across all domains. Notably, deactivation patterns revealed that some DMN regions, such as the right angular gyrus, show domain-specific deactivations and lateralization effects, underscoring the need to consistently report deactivations in creativity and biobehavioral research. While AUT robustly engages core creative networks – especially for ideation, emphasizing object manipulations – it lacks elaborative processing in other tasks, limiting its scope. Future research should prioritize reporting deactivations, examine the spatiotemporal dynamics of creative processes, investigate real-world and collaborative creativity, and embrace AI applications.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used Grammarly to correct any possible grammar mistakes. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

We have shared the data in the OSF repository

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