

# 原型线索对发散性思维影响的神经机制： 共同激活，还是个别激活？

李青青<sup>1,4</sup>, 马瑞敏<sup>2</sup>, 朴炳基<sup>3</sup>, 周爱保<sup>4\*</sup>

(1. 兰州文理学院教育学院, 兰州 730070; 2. 昆明学院学前与特殊教育学院, 昆明 650214;

3. 韩国全北国立大学, 全州 54896; 4. 西北师范大学心理学院, 兰州 730070)

**摘要:**作为创造力的关键组成部分, 发散性思维已被证明依赖于执行控制网络和默认模式网络的共同激活。且已有的元分析表明, 不同领域的发散性思维激活的大脑区域也不同, 但不同的原型启发线索依赖何种认知神经机制仍然未知。研究采用 ALE 元分析的方法比较了不同原型启发线索与发散性思维相关的大脑区域的差异。结果表明, 使用词语线索时左侧顶下小叶、左侧额下回、额中回、左侧额内侧回、右侧舌回以及左侧额下回区域被激活; 句子线索则主要与两侧额下回区域有密切的关系; 使用图片线索刺激时左侧额下回和额中回区域被激活; 使用音乐线索时则主要激活了左侧额内侧回区域。这表明在执行发散性思维任务时, 不同类型的原型启发线索与个体不同的认知功能相关。

**关键词:**原型线索; 功能性磁共振; 元分析; 发散性思维; 神经机制

中图分类号: B842.5

文献标志码: A

文章编号: 1003 - 5184(2025)06 - 0515 - 11

## 1 引言

创造性思维是推动科学发展, 引导人类文明进步的基石, 不仅在计算机开发、治疗疾病、探索宇宙、机器人研发等 21 世纪的新兴产业领域, 而且在科学艺术领域甚至日常生活问题的解决中都发挥着重要作用, 被联合国科教文组织国际教育局称为人类的未来的关键能力 (Lucas & Venekute, 2020; Marope, Griffin, & Gallagher, 2017; Ruiz - del - Pino, Fernández - Martín, & Arco - Tirado, 2022; Zhao, Wang, & Huang, 2019)。诸多研究表明, 创造性思维不是一种固定的天生特质, 是可以通过后期学校教育培养的技能, 尤其发散性思维的训练在个体创造力发展中发挥着关键作用 (Puccio, 2017; Ritter, Gu, Crijns, & Biekens, 2020; Ritter & Mostert, 2017)。发散性思维是指从一个给定的目标出发, 突破现有的知识范围, 以一种开放、新颖且有意义的方式组合知识, 从而产生大量独特的想法的思维方式。被认为是创造性思维的关键组成部分 (Guilford, 1987; Mekern, Hommel, & Sjoerds, 2019; Runco, 1991)。

发散性思维作为一种高级又复杂的认知活动, 仅仅依靠量表开发、行为观察等方式进行研究对发散性思维相关的认知加工过程的认识是有限的

(Zhou, 2018)。因此越来越多的研究通过认知神经的方法来探究发散性思维与大脑结构和功能的相关关系 (Abdul Hamid et al., 2019; Chrysiou et al., 2020)。虽然以认知神经为基础进行的研究越来越多, 但是单个神经成像的研究可能存在假阳性 (false positives) 的问题, 诸多研究证明单个认知神经研究方法出现假阳性的概率高达 15% (Yarkoni, Poldrack, Van Essen, & Wager, 2010; Wager, Lindquist, & Kaplan, 2007)。因此, 越来越多的元分析方法逐渐被广泛地应用于认知神经的研究中。激活似然性评估 (activation likelihood estimation, ALE) 作为最常见的基于坐标的元分析, 整合了大量的脑成像研究结果, 通过自动化的统计分析得到稳定的脑激活区域 (Radua & Mataix - Cols, 2012)。将实验中报告的坐标值进行统计寻找空间位置的一致性, 相比之前的元分析操作更为严谨客观, 能够提升结果的科学性 (邓沁丽, 陈俊, 2015; Eickhoff, Laird, Grefkes, Wang, Zilles, & Fox, 2009)。

目前关于发散性思维认知神经机制的研究多集中在比较不同领域发散性思维的大脑激活模式。有研究比较了音乐、语言以及视觉空间领域的创造力, 结果表明, 不同领域的创造力与不同的大脑区域相

\* 通信作者: 周爱保, E-mail: zhouab@nwnu.edu.cn。

关联(Boccia et al., 2015)。视觉空间领域和语言领域的发散性思维依赖两种不同形式的大脑功能偏侧化。视觉空间领域的发散性思维与视觉网络、额顶网络以及默认网络之间的功能连接有关,而语言领域的发散性思维则依赖于复杂语义加工网络和认知控制加工网络(Chen et al., 2019)。此外,另一项元分析对比了绘画、文学以及音乐领域创造性的神经关联。结果表明,虽然不同的领域有共同的通用神经系统,但是在各个领域都有各自特定的神经回路(Chen, Beaty, & Qiu, 2020)。然而研究者对创造力领域的划分标准存在较大的差异,或以不同学科作为标准,或以任务或内容作为标准,致使创造力领域的研究面临较大的困境(蔺素琴等, 2016)。按照创造力的投资理论观点,原型知识不仅是领域创造力表现的信息来源,而且可以作为判断个体表现的重要指标。不同领域的创造力在必要的原型知识结构和创造性思维技能方面有很大的差异(Huang et al., 2017; 蔺素琴等, 2016)。研究表明,不同领域关联的原型知识储备决定了创造力的领域特殊性,拥有某个领域的原型知识储备更丰富的个体更有可能在关联领域有更高的创造力(Acar & Van Den Ende, 2016; An, Song, & Carr, 2016; Kaufman et al., 2013)。故而拥有更多知识经验的专家组和新手组在评定创造力诗歌和小说作品时会呈现较大的差异,专家组在前额叶皮层的脑电波段平均水平显著高于新手组(Kaufman et al., 2013; Liang, Chang, & Liu, 2019)。由此可见,原型在领域性创造力中发挥着关键作用。既然不同领域的发散性思维有特定的神经回路,那么,不同的原型启发线索是否也有各自特定的神经回路呢?有研究认为创造性思维的核心成分应该是“原型的激活”,而原型被认为可能是主试提供的“原型问题”在被试头脑中的表征,也可能是被试头脑中已有的相关知识经验,还可能是被试在解决当前顿悟问题的过程中发现的有启发作用的认知信息(朱海雪等, 2020)。国内已有研究证明了原型数量、原型的呈现时间(保留或消失)、原型启发的位置(前或后)、原型呈现的方式(文本或图形)及难易程度对个体的创造性思维表现都有影响(陶爱华, 2013; 邢强, 王蕊等, 2016; 杨文静, 靳玉乐等, 2018; 朱海雪, 朱承亮等, 2020)。但国内大部分对原型机制的探索研究都是以顿悟、科学解决问题为主要的研究内容且较少基于 fMRI 等认知神经科学技术。对原型与不同领域创造性先行研究表明在使

用词语线索时,额上回、左侧枕叶和顶叶、左侧颞中回等大脑区域被激活(Benedek, Jauk, Beaty, Fink, Koschuting, & Neubauer, 2016)。但是在使用图片线索的研究中,额下回、颞下回、缘上回等大脑区域被激活(Perchtold et al., 2018)。因此,为了进一步探索不同原型启发线索下发散性思维的认知神经机制,本研究拟通过 4 个单独的 ALE 元分析,评估不同原型启发线索下发散性思维关联的大脑区域,以期更加全面、具体地了解发散性思维的认知神经机制。

## 2 发散性思维认知神经科学的元分析

### 2.1 元分析文献检索、筛选及编码

在 Google scholar、Web of Science、NeuroSynth、X-mol 等数据库检索 2003 年至 2023 年题目、摘要或关键词中包含“creativity”、“divergent thinking”、“alternative uses task”、“creativity writing”、“creativity thinking”、“story generation”、“metaphor”、“original idea”、“idea generation” AND “brain imaging”、“cerebral correlates”、“neural”、“neuroimaging”、“functional magnetic resonance”的文献。

研究的纳入标准为:(1)纳入的研究必须使用 fMRI 进行全脑分析,因此排除了 PET 及 ROI 研究;(2)报告的激活坐标位于 MNI 或 Talairach 空间;(3)研究对象必须为健康人群;(4)报告中必须标明使用哪种类型的原型启发线索。最终共纳入 48 篇文献包含 49 个独立研究,其中包括词语线索 27 个、句子线索 12 个、图片线索 6 个以及音乐线索 4 个。文献筛选流程见图 1。对纳入研究文献的作者信息、样本量、男性数量、年龄、任务、线索类型以及坐标空间类型(见表 1)进行编码。

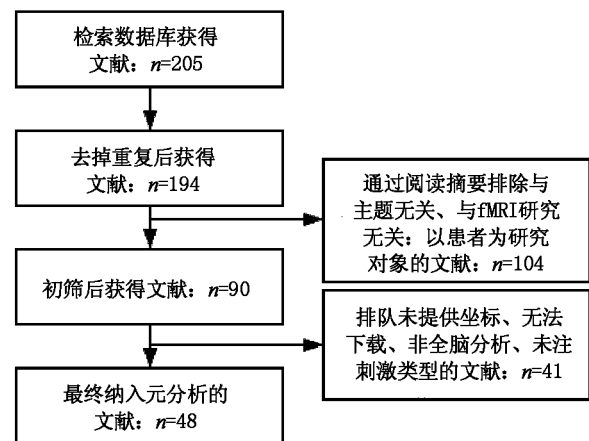


图 1 元分析文献筛选流程

表1 纳入元分析原始研究基本资料

作者、发表时间	<i>N</i>	<i>M</i>	年龄	任务	线索类型	坐标空间
AbdulHamid(2019)	50	-	-	多用途测验	图片	MNI
Abraham(2012)	19	8	19-29	多用途测验	词语	Talairach
Abraham(2014)	28	14	22.79	多用途测验	词语	Talairach
Abraham(2018)	43	-	-	多用途测验	词语	MNI
Amir(2016)	22	19	20-47	对给定的图片生成 创意性题目	图片	Talairach
Aziz-Zadeh(2013)	13	6	23.15	图形再构成	图片	MNI
Bambini(2011)	9	5	25	隐喻任务	句子	Talairach
Beaty(2015)	25	12	18-30	多用途测验	词语	MNI
Beaty(2017)	24	9	18-47	关联创意性词语 生成任务	词语	MNI
Benedek(2014)	28	10	19-49	隐喻任务	句子	MNI
Benedek(2014)b	35	11	18-29	多用途测验	词语	MNI
Benedek(2016)	32	13	28.3	创意性句子生成	词语	MNI
Benedek(2018)	42	17	19-36	多用途测验	词语	MNI
Bengtsson(2007)	11	11	23-41	即兴创作	音乐	MNI
Berkowitz(2008)	12	-	21.9	即兴创作	音乐	Talairach
Bitsch(2021)	24	12	23-56	多用途测验	词语	MNI
Chrysikou(2020)	36	17	51.8	多用途测验	图片	MNI
Diaz(2011)	16	8	21-31	隐喻任务	句子	MNI
Diaz(2011)b	16	8	18-30	隐喻任务	句子	MNI
Ellamil(2012)	15	6	22.14	根据书本描述生成 创意性图片	句子	MNI
Erhard(2014)	48	26	-	头脑风暴	句子	MNI
Fink(2009)	21	10	20-32	多用途测验	词语	MNI
Fink(2010)	31	13	19-29	多用途测验	词语	MNI
Fink(2012)	24	10	21-30	多用途测验	词语	MNI
Fink(2015)	53	27	19-34	多用途测验	词语	MNI
Green(2015)	55	31	22.5	关联创意性词语 生成任务	词语	MNI
Hartung(2020)	27	-	19-36	隐喻任务	句子	MNI
Heinonen(2016)	16	4	19-49	多用途测验	图片	MNI
Howard-Jones(2005)	8	1	19-28	创意性故事生成	词语	MNI
Huang(2018)	20	9	21-26	判断给定谜题的答案 创意性与否	句子	MNI
Ivancovsky(2018)	36	-	28.93	多用途测验	词语	Talairach
Kaiser(2013)	19	7	21-34	特殊情境创意性行动 生成任务	句子	MNI
Kleibeuker(2017)	32	18	15-16	多用途测验	词语	MNI
Kroger(2012)	19	9	19-31	多用途测验	词语	MNI
Lee(2006)	12	6	23-35	隐喻任务	词语	Talairach
Liu(2012)	12	12	23-36	即兴创作	音乐	MNI
Mashal(2007)	15	8	21-31	隐喻任务	词语	Talairach
Mayseless(2015)	25	-	-	多用途测验	词语	Talairach
Perchtold(2018)	45	14	18-34	多用途测验	图片	MNI
Rapp(2004)	15	9	15.3	隐喻任务	句子	Talairach
Rutter(2012)	18	9	22.78	隐喻任务	句子	MNI
Shah(2013)	28	14	24	头脑风暴	词语	MNI

续表 1

作者、发表时间	<i>N</i>	<i>M</i>	年龄	任务	线索类型	坐标空间
Shibata(2007)	13	8	21 - 29	隐喻任务	句子	Talairach
Sun(2016)	28	11	-	多用途测验	词语	MNI
Vartanian(2014)	13	10	32.23	多用途测验	词语	MNI
Vartanian(2018)	44	31	20 - 56	多用途测验	词语	MNI
Villareal(2013)	24	9	21.9	即兴创作	音乐	MNI
Zhang(2014)	18	8	17 - 23	隐喻任务	词语	Talairach

## 2.2 元分析程序

ALE 元分析的基本原理是将每个实验中的激活焦点拟合为概率分布,并通过自动统计分析获得稳定的大脑激活区域(Radua & Matax - Cols, 2012; Tureltaub, Eden, Jones, & Zeffiro, 2002)。本研究对 27 个使用词语线索包含 608 个焦点的研究,12 个使用句子线索包含 199 个焦点的研究,6 个使用图片线索包含 136 个焦点的研究以及 4 个使用音乐线索包含 54 个焦点的研究分别用 Ginger ALE 3.0.2 (<http://www.brainmap.org/>) 软件进行了四个独立的 ALE 元分析。

使用 Ginger ALE 中的 tal2icbm - spm 将 Talairach 坐标转换为 MNI 坐标,根据 Muller 等人(2018)的最新计算方法使用 1000 次反复置换,为了克服假阳性将体素簇水平(cluster level)的族错误率

(familywise error, FWE) 设置为  $p < 0.05$ ,体素簇形成(cluster forming)体素水平(voxel level)的特定阈值设置为  $p < 0.001$ 。分析结果使用 Mango 4.0.1 (<http://ric.uthscsa.edu/mango/>) 软件进行可视化呈现。

## 3 结果

### 3.1 词语线索相关大脑区域

ALE 分析结果表明,当执行发散性思维任务使用词语线索时共激活了 5 个体素簇(表 2)。第 1 个体素簇体积大小为  $2544 \text{ mm}^3$ ,被激活的脑区为左侧顶下小叶;第 2 个体素簇体积大小为  $2520 \text{ mm}^3$ ,被激活的脑区为左侧额下回和额中回;第 3 个体素簇体积大小为  $1664 \text{ mm}^3$ ,被激活的脑区为左侧额内侧回;第 4 个体素簇体积大小为  $1104 \text{ mm}^3$ ,被激活的脑区为右侧舌回;第 5 个体素簇体积大小为  $848 \text{ mm}^3$ ,被激活的脑区为左侧颞下回(图 2)。

表 2 词语线索相关大脑区域及坐标

Cluster	Vol( $\text{mm}^3$ )	Region	H <sup>a</sup>	BA <sup>b</sup>	x	y	z	ALE <sup>c</sup>
1	2544	Inferior parietal lobule	L	40	-58	-32	40	0.0452
2	2520	Inferior frontal gyrus	L	44	-48	14	14	0.0364
		Middle frontal gyrus	L	9	-48	18	24	0.0216
3	1664	Medial frontal gyrus	L	6	-6	20	46	0.0393
		Medial frontal gyrus	L	6	-4	10	58	0.0200
4	1104	Lingual gyrus	R	18	20	-90	-4	0.0246
		Lingual gyrus	R	17	16	-94	4	0.0204
5	848	Inferior temporal gyrus	L	37	-50	-68	2	0.0247

注:a H = Hemisphere (R:right;L:left);b BA = Brodmann Area;c ALE = Extreme ALE Value

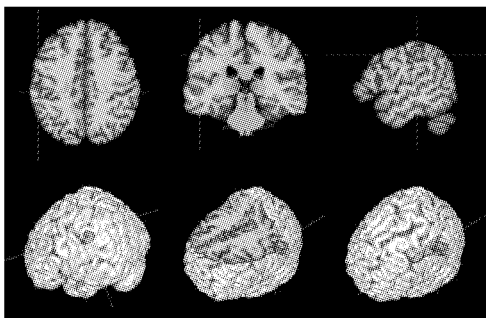


图 2 执行发散性思维任务使用词语线索时被激活的大脑区域

注:十字线交叉的大脑区域为左侧顶下小叶

### 3.2 句子线索相关大脑区域

元分析结果显示,当执行发散性思维任务使用句子线索时共激活了 2 个体素簇(表 3)。第 1 个体素簇体积大小为  $1584 \text{ mm}^3$ ,被激活的脑区为右侧额下回;第 2 个体素簇体积大小为  $736 \text{ mm}^3$ ,被激活的脑区为左侧额下回(图 3)。

表3 句子线索相关大脑区域及坐标

Cluster	Vol(mm <sup>3</sup> )	Region	H <sup>a</sup>	BA <sup>b</sup>	x	y	z	ALE <sup>c</sup>
1	1584	Inferior frontal gyrus	R	45	54	28	10	0.0227
2	736	Inferior frontal gyrus	L	47	-48	28	-8	0.0167
		Inferior frontal gyrus	L	47	-50	22	-12	0.0216

注:a H = Hemisphere(R:right;L:left);b BA = Brodmann Area;c ALE = Extreme ALE Value

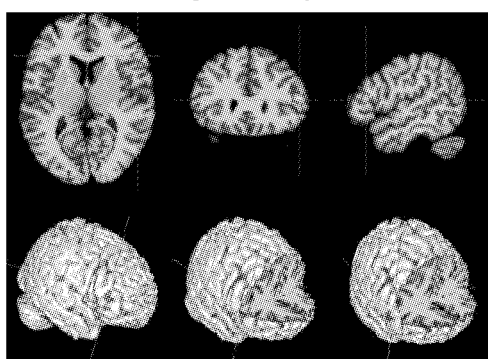


图3 执行发散性思维任务使用句子线索时被激活的大脑区域

注:十字线交叉的大脑区域为右侧额下回

表4 图片刺激相关大脑区域及坐标

Cluster	Vol(mm <sup>3</sup> )	Region	H <sup>a</sup>	BA <sup>b</sup>	x	y	z	ALE <sup>c</sup>
1	688	Inferior frontal gyrus	L	9	-44	10	28	0.0166
		Middle frontal gyrus	L	9	-42	14	26	0.0157

注:a H = Hemisphere(R:right;L:left);b BA = Brodmann Area;c ALE = Extreme ALE Value

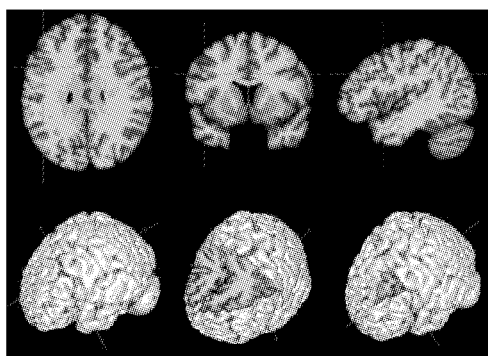


图4 执行发散性思维任务使用图片线索时被激活的大脑区域

注:十字线交叉的大脑区域为左侧额下回

表5 音乐线索相关大脑区域及坐标

Cluster	Vol(mm <sup>3</sup> )	Region	H <sup>a</sup>	BA <sup>b</sup>	x	y	z	ALE <sup>c</sup>
1	1120	Medial frontal gyrus	L	6	-22	10	50	0.0116
2	792	Medial frontal gyrus	L	32	-8	16	48	0.0143

注:a H = Hemisphere(R:right;L:left);b BA = Brodmann Area;c ALE = Extreme ALE Value

#### 4 讨论

本研究主要通过4个独立的ALE元分析比较了在执行发散性思维任务时,不同类型的原型启发

#### 3.3 图片线索相关大脑区域

ALE分析结果表明,当执行发散性思维任务使用图片线索时共激活了1个体素簇(表4)。体素簇体积大小为688 mm<sup>3</sup>,被激活的脑区为左侧额下回和额中回(图4)。

#### 3.4 音乐线索相关大脑区域

元分析结果显示,当执行发散性思维任务使用音乐线索时共激活了2个体素簇(表5)。第1个体素簇体积大小为1120 mm<sup>3</sup>,被激活的脑区为左侧额内侧回;第2个体素簇体积大小为792 mm<sup>3</sup>,被激活的脑区为左侧额内侧回(图5)。

线索下激活的大脑区域间差异。当执行发散性思维任务使用词语线索时最大的激活区域为顶下小叶,作为默认执行网络的一部分,顶下小叶被认为在语

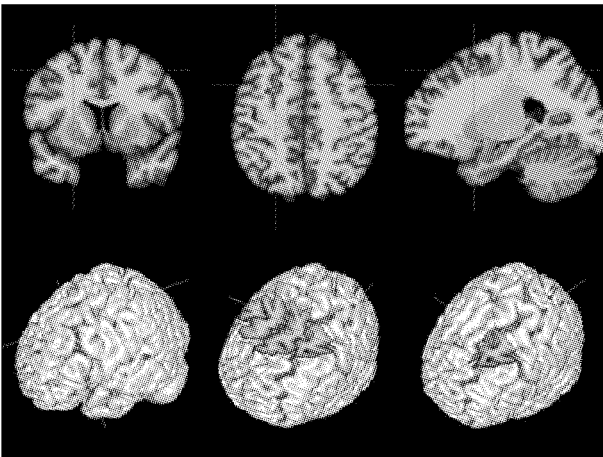


图5 执行发散性思维任务使用图片线索时被激活的大脑区域

注:十字线交叉的大脑区域为左侧额内侧回

言注意以及专注于语义和语音问题的语言相关过程中发挥了重要作用 (Barbeau et al., 2017; Montefinese, Pinti, Ambrosini, Tachtsidis, & Vinson, 2021)。已有研究表明,顶下小叶通常与言语阅读的流畅性以及视听信息的整合处理相关 (Boissonneau et al., 2022; Sun, Huang, Wang, Zhang, & Tang, 2022)。结果表明左侧额下回也被激活,该区域与语义检索以及以创新的方式整合语义概念有很大的关系,故而选择词语线索时该区域也呈现出较大的激活 (Boccia et al., 2015)。此外,额下回、额内侧回以及顶下小叶区域已被反复证明在语义加工、语义检索等语言创造力相关的过程中被激活,这些过程都需要检索生成与给定词汇相关的词汇 (McDermott et al., 2003; Tan, Larid, Li, & Fox, 2005)。大脑左侧额叶皮层与创造性地整合语义信息相关,而词汇语言类的发散性思维也被证明与左侧顶叶及颞叶区域的参加有重要联系 (Green, Cohen, Raab, Yedibalian, & Gray, 2015; Kleibeuker et al., 2017)。因此,当执行发散性思维任务时使用词语类型的原型启发线索时,大脑左侧的枕叶、额叶以及颞叶的部分区域都被激活。另外,本研究元分析结果表明,舌回区域也被激活,舌回区域被证明在词语记忆和处理过程中发挥了重要作用 (Palejwala et al., 2021)。Chen 等人 (2020) 的研究也证明舌回区域与文学领域的创造性有密切的联系。

元分析结果表明,当执行发散性思维任务使用句子线索时大脑的额下回区域被激活 (Boccia et al., 2015)。左侧额下回区域被认为在句子及文章的理解过程中发挥了重要作用 (Van der Burght, Goucha, Friederici, Kreitewolf, & Hartwigsen, 2019)。

已有研究表明该区域对创意性文章的生成至关重要,而当该区域被损伤时,个体的创造能力也有一定程度的损伤 (Benedek et al., 2016; De Souza et al., 2014; Gibson, Folley, & Pak, 2009)。右侧额下回则区域往往与注意力过程以及成功的反应抑制有很大的关系,在言语类型的创造力中发挥着重要作用 (Boccia et al., 2015)。多项研究都表明,额下回区域在言语创造力中起着重要的作用,作为前额叶皮层的重要组成部分,创意性句子、文章以及故事情节的生成能力与该区域有着密切的关系 (Dietrich & Kanso, 2010; Liu et al., 2015)。此外,Giustolisi 等人 (2018) 的研究表明,当额下回区域被阳极经颅直流电刺激 (transcranial direct current stimulation, tDCS) 时,被试对句子的理解能力得到了有效的提升。

本研究结果显示,当使用图片线索时左侧额下回及额中回区域被激活。以往使用图片线索的研究表明,额叶皮层区域在视觉性刺激、视觉性创造性以及创造性绘画过程中的参与度都有所增加 (Aziz-Zadeh, Liew, & Dandekar, 2013; De Gelder, Tamietto, Pegna, & Van den Stock, 2015; Rominger et al., 2020)。此外,以大学生为研究对象的研究发现,在大学生绘制创意性图片的过程中左侧额下回区域被显著性激活 (Huang et al., 2013; Saggar et al., 2015)。需要指出的是在先行研究中,不仅额叶区域,颞叶区域也有一定程度的激活,本研究未发现这一结果,可能是因为研究数量较少导致的。

本研究发现当执行发散性思维任务使用音乐线索时左侧额内侧回区域被激活。额内侧回区域是前扣带回皮层 (ACC) 的组成部分之一,这个区域通常被认为与情绪控制及加工过程有关 (Park, Ma, Wang, & Bak, 2020)。当被试听到音乐引起愉悦的情绪时,前扣带回皮层区域被激活 (Mikutta, Maisen, Altorfer, Strik, & Konig, 2014)。已有研究表明,听音乐过程中前扣带皮层区域不仅被激活,而且在音乐创造的过程中该区域与角回、额上回区域的功能性连接增加 (Koelsch, Cheung, Jentschke, & Haynes, 2021; Liu et al., 2015)。但是这并不意味着执行发散性思维任务时使用音乐刺激只有这个大脑区域被激活,需要更多的研究数据来进行分析验证。

目前针对发散性思维基于不同原型线索的元分析结果表明,不同的原型线索对应专门的大脑区域更程度的激活。具体来说,在执行发散性思维任务时,使用不同类型的原型启发线索时激活的大脑

区域不同。使用词语线索时左侧顶下小叶、左侧额下回、额中回、左侧额内侧回、右侧舌回以及左侧颞下回区域被激活。句子线索则主要与两侧额下回区域有密切的关系。使用图片线索时左侧额下回和额中回区域被激活。使用音乐线索时则主要激活了左侧额内侧回区域。尽管不同的线索之间存在细微的差异,但是通过结果仍然可以证明额叶区域对创意的产生至关重要。

## 5 启示与展望

基于上述发现,发散性思维作为复杂且高级的认知活动,选用不同的原型启发线索时激活的大脑区域不同。作为创造性思维的重要组成部分,发散性思维是涉及不同心理功能,可以使用不同任务和方法来进行研究的复杂认知活动。尽管如此,由于相关文献较少,因此设定标准后纳入元分析的文献数量偏少,尤其图片和音乐线索类型文献,而且各个类别的研究数量不足以进行ALE对比分析研究导致研究结果具有一定的局限性(Eickhoff et al., 2016)。此外,作为影响发散性思维的核心要素,不止原型类别,其数量、呈现的时间、呈现位置等都会对发散性思维产生一定程度的影响,但鉴于ALE研究方法本身的局限性,要求研究案例达到足够可靠的可以应用于教育实践的结论,故而该部分的影响也无法进行数量化的元分析(Muller et al., 2018)。已有研究表明,不同的原型类别对不同领域的发散性思维也有不同的影响。如果在课堂环境中增加自然景观、绿色植被等视觉刺激时,学生的视觉创造思维会增加但对语言创造思维没有影响(Studente, Seppala, & Sadowska, 2016)。而当对学生进行了一系列诗歌相关的发散性思维训练后,这些学生在诗歌创作过程中发散性思维显著提高,但对小说创作没有任何影响(Baer, 1996)。因此,未来需要更多的相关研究来佐证不同类型的原型启发线索下,不同领域发散性思维依赖的神经机制间的差异性。

## 参考文献

\* 表示元分析用到的文献

- 邓沁丽,陈俊.(2015).基于坐标的脑成像元分析方法激活似然性评估.心理科学,38(1),216-220.
- 陶爱华.(2013).原型及问题本身呈现方式对科学问题解决的影响研究.心理技术与应用,4,14-17.
- 邢强,王蕊,唐志文,孙海龙.(2016).四字谜问题解决中原型启发的时间抵消与位置效应.心理科学,39(2),312-317.

- 杨文静,靳玉乐,邱江,张庆林.(2018).问题先导下语义相似性和原型难度对原型启发的影响.心理学报,50(3),260-269.
- 朱海雪,朱承亮,张庆林.(2020).不同范式下科学发明问题解决的原型启发机制.心理科学,43(4),815-820.
- \* Abdul Hamid, K., Yusoff, A. N., Rahman, S., Osman, S. S., Azmi, N. H., Surat, S., & Ahmad Marzuki, M. (2019). Cortical differential responses during divergent thinking tasks after creativity stimulation. *Psychology & Neuroscience*, 12(3), 342-362.
- \* Abraham, A., Pieritz, K., Thybusch, K., Rutter, B., Kröger, S., Schweckendiek, J., ... Hermann, C. (2012). Creativity and the brain: Uncovering the neural signature of conceptual expansion. *Neuropsychologia*, 50(8), 1906-1917.
- \* Abraham, A., Rutter, B., Bantini, T., & Hermann, C. (2018). Creative conceptual expansion: A combined fMRI replication and extension study to examine individual differences in creativity. *Neuropsychologia*, 118, 29-39.
- \* Abraham, A., Thybusch, K., Pieritz, K., & Hermann, C. (2014). Gender differences in creative thinking: Behavioral and fMRI findings. *Brain Imaging and Behavior*, 8, 39-51.
- Agnoli, S., Zanon, M., Mastria, S., Avenanti, A., & Corazza, G. E. (2018). Enhancing creative cognition with a rapid right- parietal neurofeedback procedure. *Neuropsychologia*, 118, 99-106.
- \* Amir, O., & Biederman, I. (2016). The neural correlates of humor creativity. *Frontiers in Human Neuroscience*, 10, 597-608.
- \* Aziz-Zadeh, L., Liew, S. L., & Dandekar, F. (2013). Exploring the neural correlates of visual creativity. *Social Cognitive and Affective Neuroscience*, 8(4), 475-480.
- Baer, J. (1996). The effects of task-specific divergent-thinking training. *The Journal of Creative Behavior*, 30(3), 183-187.
- Baer, J., & Kaufman, J. C. (2005). Bridging generality and specificity: The amusement park theoretical (APT) model of creativity. *Roeper Review*, 27(3), 158-163.
- \* Bambini, V., Gentili, C., Ricciardi, E., Bertinetto, P. M., & Pietrini, P. (2011). Decomposing metaphor processing at the cognitive and neural level through functional magnetic resonance imaging. *Brain Research Bulletin*, 86(3), 203-216.
- Barbeau, E. B., Chai, X. J., Chen, J. K., Soles, J., Berken, J., Baum, S., ... Klein, D. (2017). The role of the left inferior parietal lobule in second language learning: An intensive language training fMRI study. *Neuropsychologia*, 98, 169-176.
- \* Beaty, R. E., Benedek, M., Kaufman, S. B., & Silvia, P. J. (2015). Default and executive network coupling supports creative idea production. *Scientific Reports*, 5(1), 1-14.

- \* Beaty, R. E., Silvia, P. J., & Benedek, M. (2017). Brain networks underlying novel metaphor production. *Brain and Cognition*, *111*, 163 – 170.
- \* Benedek, M., Beaty, R., Jauk, E., Koschutnig, K., Fink, A., Silvia, P. J., ... Neubauer, A. C. (2014). Creating metaphors; The neural basis of figurative language production. *NeuroImage*, *90*, 99 – 106.
- \* Benedek, M., Jauk, E., Beaty, R. E., Fink, A., Koschutnig, K., & Neubauer, A. C. (2016). Brain mechanisms associated with internally directed attention and self – generated thought. *Scientific Reports*, *6*(1), 1 – 8.
- \* Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. (2014). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage*, *88*, 125 – 133.
- \* Benedek, M., Schües, T., Beaty, R. E., Jauk, E., Koschutnig, K., Fink, A., & Neubauer, A. C. (2018). To create or to recall original ideas; Brain processes associated with the imagination of novel object uses. *Cortex*, *99*(11), 93 – 102.
- \* Bengtsson, S. L., Csíkszentmihályi, M., & Ullén, F. (2007). Cortical regions involved in the generation of musical structures during improvisation in pianists. *Journal of Cognitive Neuroscience*, *19*(5), 830 – 842.
- \* Berkowitz, A. L., & Ansari, D. (2008). Generation of novel motor sequences; The neural correlates of musical improvisation. *NeuroImage*, *41*(2), 535 – 543.
- \* Bitsch, F., Berger, P., Fink, A., Nagels, A., Straube, B., & Falkenberg, I. (2021). Antagonism between brain regions relevant for cognitive control and emotional memory facilitates the generation of humorous ideas. *Scientific Reports*, *11*(1), 1 – 12.
- Boccia, M., Piccardi, L., Palermo, L., Nori, R., & Palmiero, M. (2015). Where do bright ideas occur in our brain? Meta – analytic evidence from neuroimaging studies of domain – specific creativity. *Frontiers in Psychology*, *6*, 1195 – 1206.
- Chen, P. Z., Chang, T. C., & Wu, C. L. (2020). Effects of gamified classroom management on the divergent thinking and creative tendency of elementary students. *Thinking Skills and Creativity*, *36*, 100664.
- Chen, Q., Beaty, R. E., Cui, Z., Sun, J., He, H., Zhuang, K., ... Qiu, J. (2019). Brain hemispheric involvement in visuospatial and verbal divergent thinking. *NeuroImage*, *202*, 116065.
- Chen, Q., Beaty, R. E., & Qiu, J. (2020). Mapping the artistic brain; Common and distinct neural activations associated with musical, drawing, and literary creativity. *Human Brain Mapping*, *41*(12), 3403 – 3419.
- \* Chrysikou, E. G., Jacial, C., Yaden, D. B., van Dam, W., Kaufman, S. B., Conklin, C. J., ... Newberg, A. B. (2020). Differences in brain activity patterns during creative idea generation between eminent and non – eminent thinkers. *NeuroImage*, *220*, 117011.
- De Gelder, B., Tamietto, M., Pegna, A. J., & Van den Stock, J. (2015). Visual imagery influences brain responses to visual stimulation in bilateral cortical blindness. *Cortex*, *72*, 15 – 26.
- \* Diaz, M. T., Barrett, K. T., & Hogstrom, L. J. (2011). The influence of sentence novelty and figurativeness on brain activity. *Neuropsychologia*, *49*(3), 320 – 330.
- \* Diaz, M. T., & Hogstrom, L. J. (2011). The influence of context on hemispheric recruitment during metaphor processing. *Journal of Cognitive Neuroscience*, *23*(11), 3586 – 3597.
- Eickhoff, S. B., Laird, A. R., Grefkes, C., Wang, L. E., Zilles, K., & Fox, P. T. (2009). Coordinate – based activation likelihood estimation meta – analysis of neuroimaging data; A random – effects approach based on empirical estimates of spatial uncertainty. *Human Brain Mapping*, *30*(9), 2907 – 2926.
- Eickhoff, S. B., Nichols, T. E., Laird, A. R., Hoffstaedter, F., Amunts, K., Fox, P. T., ... Eickhoff, C. R. (2016). Behavior, sensitivity, and power of activation likelihood estimation characterized by massive empirical simulation. *NeuroImage*, *137*, 70 – 85.
- \* Ellamil, M., Dobson, C., Beeman, M., & Christoff, K. (2012). Evaluative and generative modes of thought during the creative process. *NeuroImage*, *59*(2), 1783 – 1794.
- \* Erhard, K., Kessler, F., Neumann, N., Ortheil, H. J., & Lotze, M. (2014). Professional training in creative writing is associated with enhanced fronto – striatal activity in a literary text continuation task. *NeuroImage*, *100*, 15 – 23.
- Fink, A., Benedek, M., Koschutnig, K., Pirker, E., Berger, E., Meister, S., ... Weiss, E. M. (2015). Training of verbal creativity modulates brain activity in regions associated with language – and memory – related demands. *Human Brain Mapping*, *36*(10), 4104 – 4115.
- \* Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., ... Neubauer, A. C. (2009). The creative brain; Investigation of brain activity during creative problem solving by means of EEG and fMRI. *Human Brain Mapping*, *30*(3), 734 – 748.
- \* Fink, A., Grabner, R. H., Gebauer, D., Reishofer, G., Koschutnig, K., & Ebner, F. (2010). Enhancing creativity by means of cognitive stimulation; Evidence from an fMRI study. *NeuroImage*, *52*(4), 1687 – 1695.
- \* Fink, A., Koschutnig, K., Benedek, M., Reishofer, G., Ischebeck, A., Weiss, E. M., & Ebner, F. (2012). Stimulating creativity via the exposure to other people’s ideas. *Human Brain Mapping*, *33*(11), 2603 – 2610.

- Giustolisi, B., Vergallito, A., Cecchetto, C., Varoli, E., & Lauro, L. J. R. (2018). Anodal transcranial direct current stimulation over left inferior frontal gyrus enhances sentence comprehension. *Brain and Language*, *176*, 36–41.
- \* Green, A. E., Cohen, M. S., Raab, H. A., Yedibalian, C. G., & Gray, J. R. (2015). Frontopolar activity and connectivity support dynamic conscious augmentation of creative state. *Human Brain Mapping*, *36*(3), 923–934.
- Guilford, J. P. (1987). Creativity research; Past, present and future. *Frontiers of Creativity Research; Beyond the Basics*, 61–85.
- \* Hartung, F., Kenett, Y. N., Cardillo, E. R., Humphries, S., Klooster, N., & Chatterjee, A. (2020). Context matters: Novel metaphors in supportive and non-supportive contexts. *NeuroImage*, *212*, 116645.
- \* Heinonen, J., Numminen, J., Hlushchuk, Y., Antell, H., Tattila, V., & Suomala, J. (2016). Default mode and executive networks areas: association with the serial order in divergent thinking. *PloS One*, *11*(9), e0162234.
- \* Howard-Jones, P. A., Blakemore, S. J., Samuel, E. A., Summers, I. R., & Claxton, G. (2005). Semantic divergence and creative story generation: An fMRI investigation. *Cognitive Brain Research*, *25*(1), 240–250.
- Hu, Y., Ren, Z., Du, X., Lan, L., Yu, W., & Yang, S. (2021). The shifting patterns based on six thinking hats and its relationship with design creativity. *Thinking Skills and Creativity*, *42*, 100946.
- \* Huang, F., Tang, S., Sun, P., & Luo, J. (2018). Neural correlates of novelty and appropriateness processing in externally induced constraint relaxation. *NeuroImage*, *172*, 381–389.
- Huang, P., Qiu, L., Shen, L., Zhang, Y., Song, Z., Qi, Z., . . . Xie, P. (2013). Evidence for a left over right inhibitory mechanism during figural creative thinking in healthy nonartists. *Human Brain Mapping*, *34*(10), 2724–2732.
- \* Ivancovsky, T., Kleinmintz, O., Lee, J., Kurman, J., & Shamay-Tsoory, S. G. (2018). The neural underpinnings of cross-cultural differences in creativity. *Human Brain Mapping*, *39*(11), 4493–4508.
- \* Kaiser, S., Simon, J. J., Kalis, A., Schweizer, S., Tobler, P. N., & Mojzisch, A. (2013). The cognitive and neural basis of option generation and subsequent choice. *Cognitive, Affective, & Behavioral Neuroscience*, *13*, 814–829.
- \* Kleibeuker, S. W., Stevenson, C. E., van der Aar, L., Overgaauw, S., van Duijvenvoorde, A. C., & Crone, E. A. (2017). Training in the adolescent brain: An fMRI training study on divergent thinking. *Developmental Psychology*, *53*(2), 353–372.
- Koelsch, S., Cheung, V. K., Jentschke, S., & Haynes, J. D. (2021). Neocortical substrates of feelings evoked with music in the ACC, insula, and somatosensory cortex. *Scientific Reports*, *11*(1), 1–11.
- \* Kröger, S., Rutter, B., Stark, R., Windmann, S., Hermann, C., & Abraham, A. (2012). Using a shoe as a plant pot: Neural correlates of passive conceptual expansion. *Brain Research*, *1430*, 52–61.
- \* Lee, S. S., & Dapretto, M. (2006). Metaphorical vs. literal word meanings: fMRI evidence against a selective role of the right hemisphere. *NeuroImage*, *29*(2), 536–544.
- \* Liu, S., Chow, H. M., Xu, Y., Erkkinen, M. G., Swett, K. E., Eagle, M. W., . . . Braun, A. R. (2012). Neural correlates of lyrical improvisation: An fMRI study of freestyle rap. *Scientific Reports*, *2*(1), 1–8.
- Liu, S., Erkkinen, M. G., Healey, M. L., Xu, Y., Swett, K. E., Chow, H. M., & Braun, A. R. (2015). Brain activity and connectivity during poetry composition: Toward a multidimensional model of the creative process. *Human Brain Mapping*, *36*(9), 3351–3372.
- Lucas, B., & Venckute, M. (2020). Creativity – a transversal skill for lifelong learning. An overview of existing concepts and practices; Literature review report. *JRC Research Reports*, (JRC121862).
- Malkawi, N. A. M., & Smadi, M. (2018). The Effectiveness of Using Brainstorming Strategy in the Development of Academic Achievement of Sixth Grade Students in English Grammar at Public Schools in Jordan. *International Education Studies*, *11*(3), 92–100.
- Marope, M., Griffin, P., & Gallagher, C. (2017). *Future competences and the future of curriculum*. Retrieved from International Bureau of Education website: <http://www.ibe.unesco.org/en/news/document-future-competences-and-future-curriculum>.
- \* Mashal, N., Faust, M., Hendler, T., & Jung-Beeman, M. (2007). An fMRI investigation of the neural correlates underlying the processing of novel metaphoric expressions. *Brain and Language*, *100*(2), 115–126.
- \* Mayseless, N., Eran, A., & Shamay-Tsoory, S. G. (2015). Generating original ideas: The neural underpinning of originality. *NeuroImage*, *116*, 232–239.
- McDermott, K. B., Petersen, S. E., Watson, J. M., & Ojemann, J. G. (2003). A procedure for identifying regions preferentially activated by attention to semantic and phonological relations using functional magnetic resonance imaging. *Neuropsychologia*, *41*(3), 293–303.
- Mekern, V., Hommel, B., & Sjoerds, Z. (2019). Computational models of creativity: A review of single-process and multi-process recent approaches to demystify creative cognition.

- Current Opinion in Behavioral Sciences*, 27, 47 – 54.
- Mikutta, C. A. , Maissen, G. , Altorfer, A. , Strik, W. , & König, T. (2014) . Professional musicians listen differently to music. *Neuroscience*, 268, 102 – 111.
- Montefinese, M. , Pinti, P. , Ambrosini, E. , Tachtsidis, I. , & Vinson, D. (2021) . Inferior parietal lobule is sensitive to different semantic similarity relations for concrete and abstract words. *Psychophysiology*, 58(3) , e13750.
- Müller, V. I. , Cieslik, E. C. , Laird, A. R. , Fox, P. T. , Radua, J. , Mataix – Cols, D. , . . . Eickhoff, S. B. (2018) . Ten simple rules for neuroimaging meta – analysis. *Neuroscience & Biobehavioral Reviews*, 84, 151 – 161.
- Onarheim, B. , & Friis – Olivarius, M. (2013) . Applying the neuroscience of creativity to creativity training. *Frontiers in Human Neuroscience*, 7, 656 – 666.
- Palejwala, A. H. , Dadario, N. B. , Young, I. M. , O’ Connor, K. , Briggs, R. G. , Conner, A. K. , . . . Sughrue, M. E. (2021) . Anatomy and white matter connections of the lingual gyrus and cuneus. *World Neurosurgery*, 151, 426 – 437.
- Park, S. I. , Ma, R. M. , Wang, D. P. , & Bak, B. G. (2020) . Meta – Analysis of fMRI Researches Related to Creativity. *The Journal of Child Education*, 29(2) , 113 – 138.
- \* Perchtold, C. M. , Papousek, I. , Koschutnig, K. , Rominger, C. , Weber, H. , Weiss, E. M. , & Fink, A. (2018) . Affective creativity meets classic creativity in the scanner. *Human Brain Mapping*, 39(1) , 393 – 406.
- Puccio, G. J. (2017) . From the dawn of humanity to the 21st century: Creativity as an enduring survival skill. *The Journal of Creative Behavior*, 51(4) , 330 – 334.
- Radua, J. , & Mataix – Cols, D. (2012) . Meta – analytic methods for neuroimaging data explained. *Biology of Mood & Anxiety Disorders*, 2, 1 – 11.
- \* Rapp, A. M. , Leube, D. T. , Erb, M. , Grodd, W. , & Kircher, T. T. (2004) . Neural correlates of metaphor processing. *Cognitive Brain Research*, 20(3) , 395 – 402.
- Ritter, S. M. , Gu, X. , Crijns, M. , & Biekens, P. (2020) . Fostering students’ creative thinking skills by means of a one – year creativity training program. *PLoS One*, 15(3) , e0229773.
- Ritter, S. M. , & Mostert, N. (2017) . Enhancement of creative thinking skills using a cognitive – based creativity training. *Journal of Cognitive Enhancement*, 1, 243 – 253.
- Rominger, C. , Papousek, I. , Perchtold, C. M. , Benedek, M. , Weiss, E. M. , Weber, B. , . . . Fink, A. (2020) . Functional coupling of brain networks during creative idea generation and elaboration in the figural domain. *NeuroImage*, 207, 116395.
- Ruiz – del – Pino, B. , Fernández – Martín, F. D. , & Arco – Tirado, J. L. (2022) . Creativity training programs in primary education: A systematic review and meta – analysis. *Thinking Skills and Creativity*, 46, 101172.
- Runco, M. A. (1991) . *Divergent thinking*. Norwood, NJ: Ablex.
- \* Rutter, B. , Kröger, S. , Stark, R. , Schweckendiek, J. , Windmann, S. , Hermann, C. , & Abraham, A. (2012) . Can clouds dance? Neural correlates of passive conceptual expansion using a metaphor processing task; Implications for creative cognition. *Brain and Cognition*, 78(2) , 114 – 122.
- Saggar, M. , Quintin, E. M. , Kienitz, E. , Bott, N. T. , Sun, Z. , Hong, W. C. , . . . Reiss, A. L. (2015) . Pictionary – based fMRI paradigm to study the neural correlates of spontaneous improvisation and figural creativity. *Scientific Reports*, 5(1) , 1 – 11.
- \* Shah, C. , Erhard, K. , Ortheil, H. J. , Kaza, E. , Kessler, C. , & Lotze, M. (2013) . Neural correlates of creative writing: An fMRI study. *Human Brain Mapping*, 34(5) , 1088 – 1101.
- \* Shibata, M. , Abe, J. I. , Terao, A. , & Miyamoto, T. (2007) . Neural mechanisms involved in the comprehension of metaphoric and literal sentences: An fMRI study. *Brain Research*, 1166, 92 – 102.
- Studente, S. , Seppala, N. , & Sadowska, N. (2016) . Facilitating creative thinking in the classroom: Investigating the effects of plants and the colour green on visual and verbal creativity. *Thinking Skills and Creativity*, 19, 1 – 8.
- \* Sun, J. , Chen, Q. , Zhang, Q. , Li, Y. , Li, H. , Wei, D. , . . . Qiu, J. (2016) . Training your brain to be more creative: Brain functional and structural changes induced by divergent thinking training. *Human Brain Mapping*, 37(10) , 3375 – 3387.
- Sun, M. , Wang, M. , & Wegerif, R. (2020) . Effects of divergent thinking training on students’ scientific creativity: The impact of individual creative potential and domain knowledge. *Thinking Skills and Creativity*, 37, 100682.
- Tan, L. H. , Laird, A. R. , Li, K. , & Fox, P. T. (2005) . Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: A meta – analysis. *Human Brain Mapping*, 25(1) , 83 – 91.
- Turkeltaub, P. E. , Eden, G. F. , Jones, K. M. , & Zeffiro, T. A. (2002) . Meta – analysis of the functional neuroanatomy of single – word reading: Method and validation. *NeuroImage*, 16(3) , 765 – 780.
- Van der Burght, C. L. , Goucha, T. , Friederici, A. D. , Kreitewolf, J. , & Hartwigsen, G. (2019) . Intonation guides sentence processing in the left inferior frontal gyrus. *Cortex*, 117, 122 – 134.
- \* Vartanian, O. , Beatty, E. L. , Smith, I. , Blackler, K. , Lam, Q. , & Forbes, S. (2018) . One – way traffic: The inferior frontal gyrus controls brain activation in the middle temporal gyrus and inferior parietal lobule during divergent thinking. *Neu-*

- ropsychologia, 118, 68 – 78.
- \* Vartanian, O. , Bouak, F. , Caldwell, J. L. , Cheung, B. , Cupchik, G. , Jobidon, M. E. , . . . Smith, I. ( 2014 ). The effects of a single night of sleep deprivation on fluency and prefrontal cortex function during divergent thinking. *Frontiers in Human Neuroscience*, 8, 1 – 12.
- \* Villarreal, M. F. , Cerquetti, D. , Caruso, S. , Schwarcz López Aranguren, V. , Gerschovich, E. R. , Frega, A. L. , & Leiguarda, R. C. ( 2013 ). Neural correlates of musical creativity: Differences between high and low creative subjects. *PLoS One*, 8(9), e75427.
- Wager, T. D. , Lindquist, M. , & Kaplan, L. ( 2007 ). Meta – analysis of functional neuroimaging data: Current and future directions. *Social Cognitive and Affective Neuroscience*, 2(2), 150 – 158.
- Xu, X. , & Pang, W. ( 2020 ). Can concept mapping facilitate verbal divergent thinking? *Creativity Research Journal*, 32(4), 344 – 356.
- Yarkoni, T. , Poldrack, R. A. , Van Essen, D. C. , & Wager, T. D. ( 2010 ). Cognitive neuroscience 2. 0: Building a cumulative science of human brain function. *Trends in Cognitive Sciences*, 14(11), 489 – 496.
- \* Zhang, H. , Liu, J. , & Zhang, Q. ( 2014 ). Neural representations for the generation of inventive conceptions inspired by adaptive feature optimization of biological species. *Cortex*, 50, 162 – 173.
- Zhao, Q. , Wang, X. , & Huang, C. ( 2019 ). Discussion on the Thinking Innovation by the Theory of Traditional Chinese Medicine. *J Altern Complement Integr Med*, 5(3), 65 – 66.
- Zhou, K. ( 2018 ). What cognitive neuroscience tells us about creativity education: A literature review. *Global Education Review*, 5(1), 20 – 34.

## The Neural Mechanism of the Influence of Archetypal Heuristic Cues on Divergent Thinking: Co – activation or Individual Activation?

Li Qingqing<sup>1,4</sup>, Ma Ruimin<sup>2</sup>, Piao Bingji<sup>3</sup>, Zhou Aibao<sup>4</sup>

(1. Lanzhou University of Arts and Science, School of Education, Lanzhou 730070;

2. Kunming University, College of Preschool and Special Education, Kunming 650214;

3. Jeonbuk National University, Quanzhou 54896; 4. Northwest Normal University, School of Psychology, Lanzhou 730070)

**Abstract:** Divergent thinking, a key component of creativity, has been shown to rely on the co – activation of both the executive control network and the default mode network. The existing meta – analysis shows that divergent thinking in different fields activates different brain regions, but it is still unknown which cognitive neural mechanism depends on different archetypal heuristic cues. In this study, ALE meta – analysis was used to compare the differences in brain regions associated with different archetypal heuristic cues and divergent thinking. The results showed that the left inferior parietal lobule, left inferior frontal gyrus, middle frontal gyrus, left medial frontal gyrus, right lingual gyrus and left inferior temporal gyrus were activated when word cues were used. The sentence cues are closely related to the bilateral inferior frontal gyrus. The left inferior frontal gyrus and middle frontal gyrus were activated when the picture cue was used. The left medial frontal gyrus was primarily activated when music cues were used. This suggests that different types of archetypal heuristic cues are associated with different cognitive functions when performing divergent thinking tasks.

**Key words:** archetypal heuristic cues; functional magnetic resonance imaging; meta – analysis; divergent thinking; neural mechanism