Changes in divergent thinking strategy due to creativity training: Findings from dynamic causal modelling

Abdul Hamid K¹,², Yusoff A N¹, Rahman S³, Osman S S⁴, Surat S³, Ahmad Marzuki M⁴ and Azmi N H³

¹ Diagnostic Imaging and Radiotherapy Program, Centre for Health and Applied Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Jalan Raja Muda Abdul Aziz, 50300 Kuala Lumpur, Malaysia
² Medical Imaging Department, School of Health Sciences, KPJ Healthcare University College, Persiaran Seriemas, 71800 Nilai, Malaysia
³ Department of Learning and Teaching Innovation, Faculty of Education, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
⁴ Faculty of Medicine, Universiti Kebangsaan Malaysia Medical Centre, Jalan Yaacob Latif, 56000 Kuala Lumpur, Malaysia

Corresponding author: nazlimtrw@ukm.edu.my

Abstract. Enhancing divergent thinking skills via creativity stimulation training has proven to increase performance in creativity, and caused changes in neuronal responses. However, the studies on effective connectivity between these regions has yet to be explored. This study aims to identify the most optimum connectivity model between left angular gyrus (AG), left precuneus (PCU) and medial prefrontal cortices (mPFC) during divergent thinking task in 36 healthy volunteers. All participants performed a behavioral alternative use test (AUT) and were divided into two groups, in which experimental group received creativity training, and control group were void of it. Both groups then underwent functional magnetic resonance imaging (fMRI) data acquisition, in which participants were instructed to alternative use test (AUT) of the common household object visually projected to them in the MRI bore. Post-fMRI AUT assessment was also done. Data were analysed using Statistical Parametric Mapping (SPM12) and Dynamic Causal Modelling (DCM12.5) software. Findings revealed full bidirectional connectivity between left AG, left PCU and mPFC during execution of alternative use generation. Creativity stimulation training has impacted in the change of input centre to be on left AG in the control group and mPFC in the experimental group, implying different divergent thinking strategies among participants who attended the creativity training.

1. Introduction
Divergent thinking is an important indicator of creativity, measured in terms of fluency, flexibility, originality and elaboration. In adapting to new environment, divergence and flexibility in thinking is essential in the young adulthood to execute useful insights and apply problem solving and decision making. To generate novel but useful ideas and execute creative solution, training of creativity stimulation has been evidenced to be effective in improving divergent thinking skills [1-3]. Enhanced creativity skills are related to difference in neuronal responses in the brain cortices, and are measurable through functional magnetic resonance imaging (fMRI). Previous fMRI studies have proven functionally specialised areas to various creativity tasks, such as prefrontal cortices in creative ideation [4], inferior parietal lobe in attention control [5] and idea generation [6], and precuneus in information
gathering [7]. Despite these evidences, studies on effective connectivity between these regions are still sparse. Thus, this study is aimed to (1) identify the optimum causal model to explain the effective connectivity between several brain regions in creativity during execution of idea generation task, and (2) investigate the impact of creativity stimulation training on these causal pathways.

2. Methodology

2.1. Participants and pre-fMRI cognitive assessment

A total of healthy 36 participants (14 male) were recruited for this study. All participants had no history of neurological or cognitive disorder. Written consent was obtained from all participants, and ethical clearance was obtained from Institutional Ethics Committee (IEC) of Universiti Kebangsaan Malaysia (UKM/PPI/111/8/JEP-2016-307). Nineteen (19) participants volunteered to be in the experimental group (mean age = 21.61 ± 0.60 years), whilst the remaining 17 was assigned to the control group (mean age = 21.28 ± 0.28 years). The experimental group received creativity stimulation training before the neurological data acquisition, while the control group were void of it.

Both groups completed a behavioural assessment prior to the training and/or fMRI data acquisition. Participants performed an adapted version of the alternative use test (AUT) [8] to quantify their divergent thinking, during which they had to generate as many alternative uses of common household items as possible. The time to complete the task was limited to 30 minutes per participant, and the score between groups were compared using an independent t-test at a significance level of $p < 0.05$.

2.2. Creativity stimulation training

Right after the pre-fMRI cognitive assessment, the experimental group of participants underwent a creativity stimulation training, that was delivered 1 week prior to the fMRI scanning session. Participants were taught to maximise the generation and variability of alternative uses of common objects based on experiential and brainstorming techniques. The objects used as the training medium were different from those used in the pre-fMRI cognitive assessment.

2.3. fMRI data acquisition and experimental stimulation

The neurological data was acquired using a 3-tesla MRI scanner (Siemens Magnetom Verio, Universiti Kebangsaan Malaysia). T2*-weighted functional images were acquired using gradient echo-echo planar imaging sequence with the following parameters: echo time = 30 ms, repetition time = 2 s, flip angle ($\alpha$) = 90°, slice thickness 3.0 mm, slice gap = 0.6 mm, field of view = 192 mm, matrix size = 64 × 64 and voxel size = 3.0 × 3.0 × 3.0 mm.

Stimulus was presented to the participant as a picture of common household object, projected visually while they were being scanned in the MRI bore. The 10 objects used in fMRI data acquisition were different from those used in the cognitive assessment and creativity training. Each object was presented for 20 s and alternated with 12 s of fixation. The total length of scan is 5.5 minutes.

2.4. fMRI data analysis

The demographic and behavioural data were analysed using IBM SPSS Statistics for Windows, version 21 (IBM Corp., Armonk, N. Y. USA). The functional image data were processed using Matlab 9.5 - 2018b (Mathworks Inc., MA, USA) and Statistical Parametric Mapping (SPM12) (Functional Imaging Laboratory, Wellcome Department of Imaging Neuroscience, Institute of Neurology, University College of London, UK).

The functional images underwent slice timing correction, realignment, normalisation and smoothing. These data were redefined using general linear model (GLM) for each participant and a design matrix was constructed and estimated. The group analyses were done via random-effect analysis, in which the cortical activation were height-thresholded at $\alpha = 0.05$ corrected to account for family-wise error (FWE) for both control and experimental groups.
2.5. Dynamic causal modelling

Based on the group activation, three regions of interest (ROIs) were extracted for dynamic causal modeling analysis, which are left angular gyrus (AG), left precuneus (PCU) and medial prefrontal cortex (mPFC). The time series signal from these three ROIs were centered at -30, -58, 34 (left AG), -16, -56, 68 (left PCU) and -4, 20, 42 (mPFC) for control group; and -26, -54, 36 (left AG), -16, -58, 68 (left PCU) and -2, 24, 44 (mPFC) for experimental group. The individual coordinates were extracted in the same region and does not exceed 16 mm distance from the group reference coordinates.

Nine (9) causal models were then specified and constructed using the extracted time series signals from left AG, left PCU and mPFC (Fig. 1). The input were centred at left AG for Models 1, 4 and 7, left PCU for Models 2, 5 and 8, and mPFC for Models 3, 6 and 9. Bidirectional intrinsic connectivity was constructed for Models 1, 2 and 3; and one directional connections was constructed for Models 4 to 9, in which Models 4, 5 and 6 has an opposite direction to Models 7, 8 and 9. These models were then estimated using spectral DCM (spDCM). The models were then compared by means of Bayesian Model Selection (BMS) for group studies using the random effect analysis (RFX) framework to obtain the optimal model that best balances between accuracy and complexity.

![Figure 1. Nine causal constructed using Dynamic Causal Modelling](image)

3. Results and Discussion

3.1. Behavioural data

Using independent samples t-test, behavioural scores from the pre-fMRI assessment was not significantly different between both groups (p > 0.05). However, post-fMRI assessment showed that the experimental group scored significantly higher (mean score = 84.53 ± 34.22) than control group (mean score = 65.41 ± 16.68) (p = 0.044).

3.2. Model comparison

The BMS revealed that the model with highest expected and exceedance probability is Model 1 for control group (Fig. 2) and Model 3 for experimental group (Fig. 3), exhibiting full bidirectional intrinsic connection between left AG, left PCU and mPFC during the alternative uses generation. However, the external input is centred at left AG for control group and mPFC for experimental group.

DCM for fMRI uses a simple deterministic model of neural dynamics of n interacting brain regions [9] that models the change of a neuronal state vector x in time. Based on Fig. 2 and 3, Model 1, 2 and 3 showed the highest expected and exceedance probability for both groups. A fully bidirectional connection is preferred over unidirectional connection, indicating fully integrated causal pathways between left AG, left PCU and mPFC during execution of alternative use task. However, the input centre is different between both groups. The input region embodies the highest influence of exogenous input among all DCM nodes that causes perturbation of hidden states, causing the highest rate of change of neural response. Difference in input region can be contributed by the difference in idea generation techniques applied by both groups of participants. Left AG is selected as input centre in control group due to its involvement in creative cognition during generation of alternative uses as
opposed to object characteristics [4]. On the other hand, prefrontal cortices has been linked to increased creativity performance in adults versus adolescents [10]. Different subareas of prefrontal cortices is suggested to play specific role to different processes of creativity, including flexibility, fluency, planning or working memory [11]. This justification explains the mPFC as the input centre for experimental group, reflecting a strategised thinking means to generate the most creative ideas.

![Figure 2](image1.png)  
**Figure 2.** (a) The optimum Model 1 by Bayesian model selection for control group, (b) The expected and exceedance probability for all models indicating that Model 1 as the optimum model

![Figure 3](image2.png)  
**Figure 3.** (a) The optimum Model 3 by Bayesian model selection for experimental group (b) The expected and exceedance probability for all models indicating that Model 3 as the optimum model

4. Conclusion  
The study revealed that the optimum connectivity model has a full directional connection between left AG, left PCU and mPFC during idea generation tasks. The region perturbed by the external input is different according to the divergent thinking method, contributed by the creativity stimulation training.

5. References  
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