# Neural dynamics of generating and evaluating creative and non-creative ideas

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## Introduction

Creativity has been shown to involve generating novel ideas and evaluating their appropriateness, relaying at the brain level on the Default Mode Network (DMN) and Executive Control Network (ECN).

However, little is known about the neural dynamics across these systems in relation to creative thinking.

Using a novel within-subject design, we apply network neuroscience methodologies to examine the flexible reconfiguration of brain regions related to generation and evaluation of creative and non-creative ideas.

## Methods

### Participants

42 participants were recruited from the University of Pennsylvania (26 women, mean age = 22.50 y, SD = 3.3 y). All participants had normal or corrected-to-normal vision and reported no history of neurological disorder, cognitive disability, or medication.

### fMRI

- Slice accelerated multiband EPI pulse sequence.
- TR = 500 ms; TE = 30 ms; flip angle = 30◦; voxel size = 3.0 mm × 3.0 mm × 3.0 mm; field of view = 192 mm.
- Motion corrected.
- WM, GM, motion, and physiological regressors removed.
- Temporally filtered.

### Functional Network Construction

Whole-brain networks were constructed for each participant. We used the Lausanne atlas, which consists of 234 ROIs, providing whole-brain coverage. Mean BOLD signal was extracted from each ROI, and bivariate correlations were computed between each pair of ROIs, resulting in a 234x234 ROI wavelet coherence connectivity matrix. The Schaefer et al. (2018; **Fig. 1**) partitions of the whole-brain into sub-systems were used, to examine system-level effects.

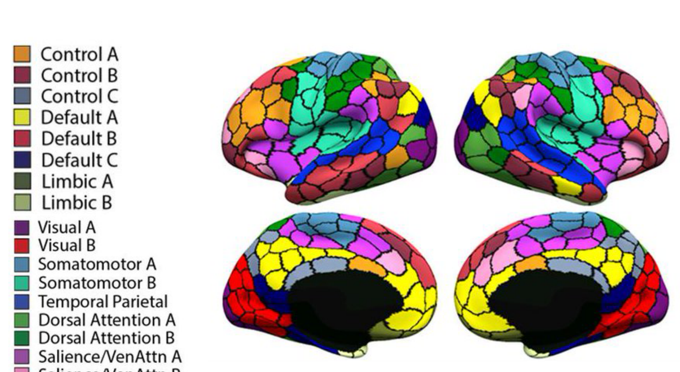


**Fig. 1.** Schaefer et al. (2018) partition into 17 neural systems.

## Generation – Evaluation Tasks

Participants completed two fMRI sessions, taking place a week a part. In the first imaging session, participants were presented with common objects (**Fig. 2**), and generated either creative (alternative uses; **AU**) or non-creative (common characteristics; **CC**) responses to common objects (**Fig. 3A**). In the second imaging session, participants evaluated their own creative and non-creative responses to the same objects (**Fig. 3B**).

**Fig. 2.** Examples of objects used to either generate and evaluate creative (alternative uses; 32 objects) or non-creative (common characteristics; 32 objects) responses.

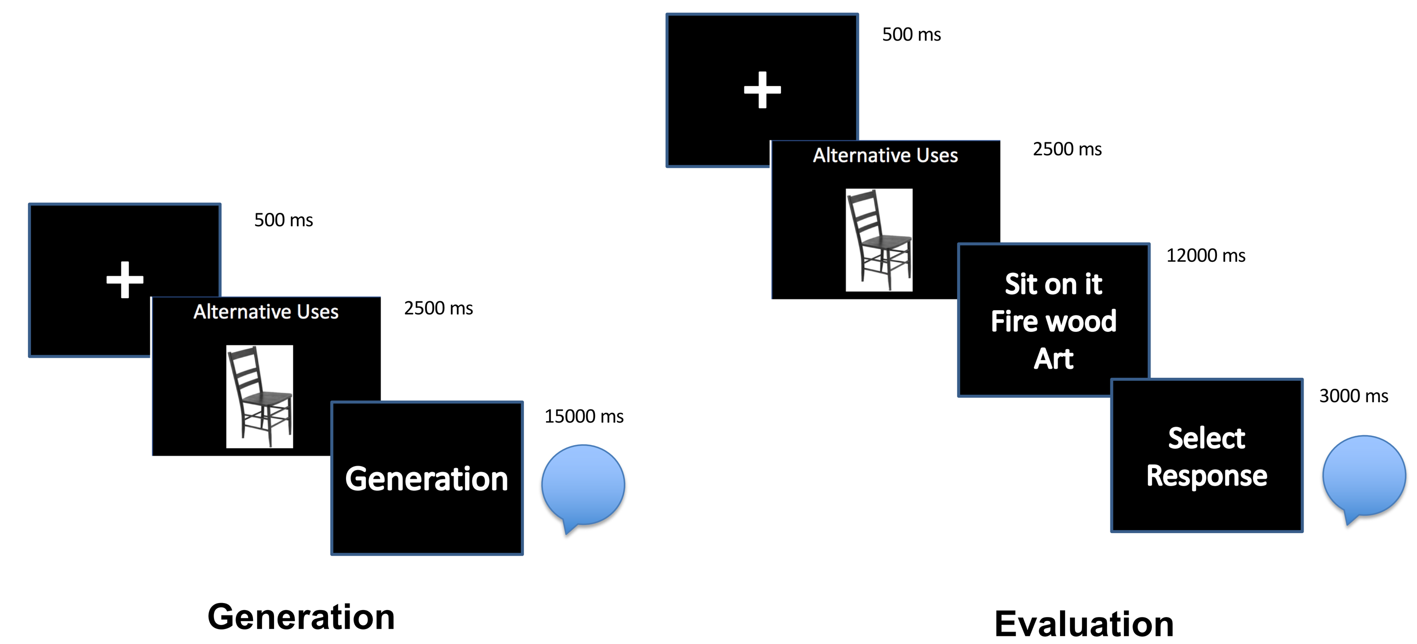


**Fig. 3.** Trial structure of the generation (A) and evaluation (B) tasks.

## Neural Flexibility Analysis

Wavelet coherence functional connectivity matrices were computed for each trials. Creative and non-creative stimuli trials were coupled together to a multilayer 32-layer network. Dynamic community detection techniques were used to extract functional communities of brain regions and characterize how they flexibly reconfigure over time **(Fig. 4).**

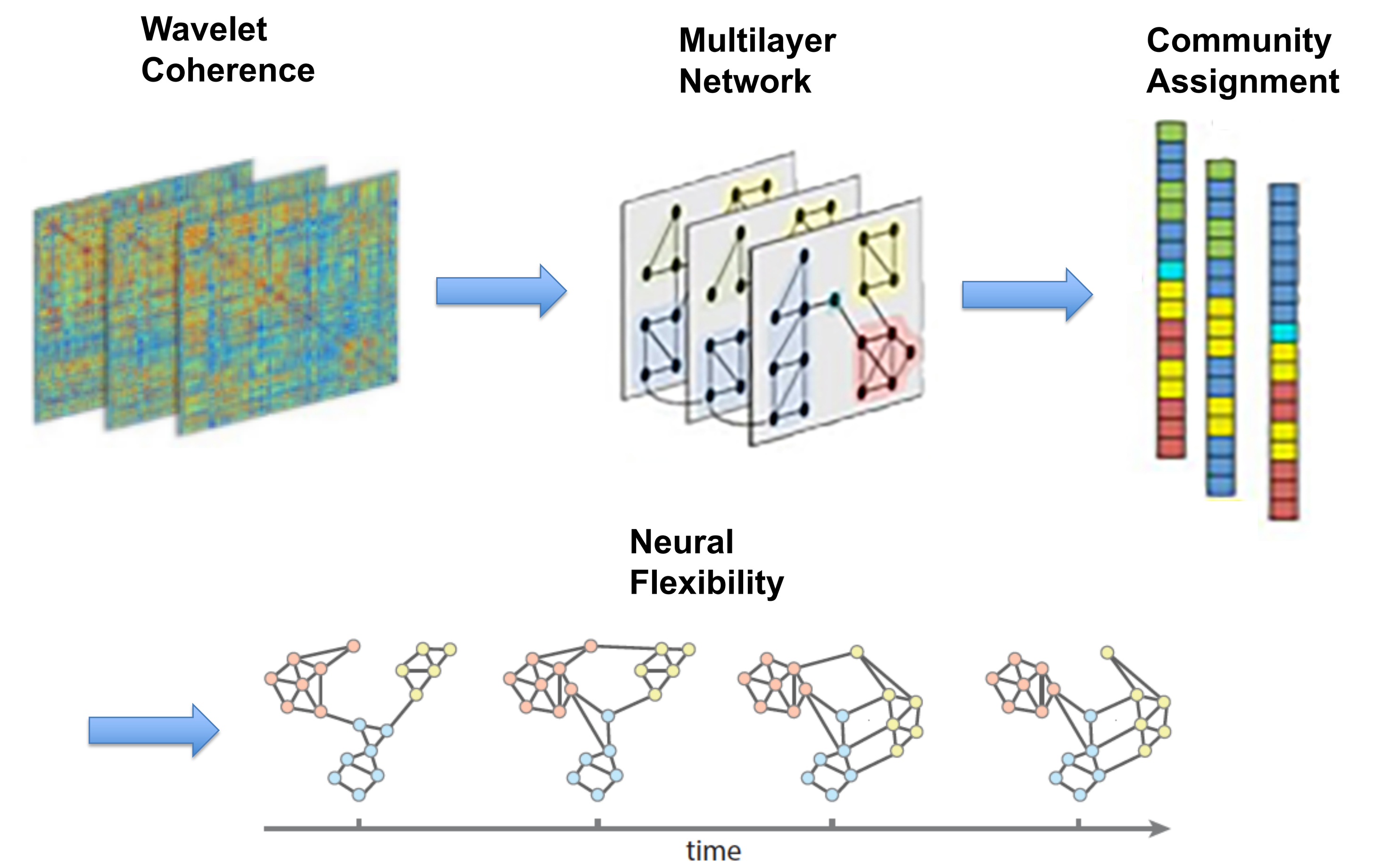


**Fig. 4.** Computing network flexibility.

## Results

Fluency (number of responses) and Creativity (subjective scores) were measured for all participants for both conditions **(Fig. 5A)**. Whole-brain neural flexibility was measured and compared across all conditions **(Fig. 5B),** and also referenced to a null model **(Fig. 5C)**. Next, we correlated individual differences of non/creative fluency and creativity scores with the four neural flexibility measures (**Table** 1). Finally, we examine how neural flexibility at the system level correlates with the four behavioral measures **(Fig. 6)**.

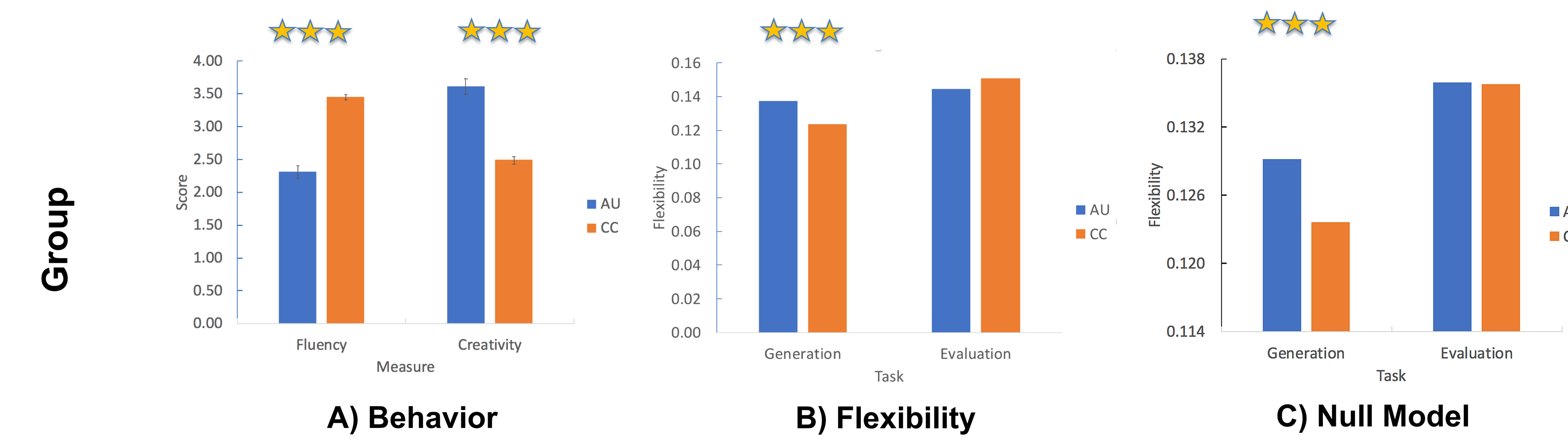


**Fig. 5.** Group-based analysis: A) Generating creative responses leads to fewer responses compared to non-creative process, but these responses are rated as more creative by independent judges. B) Whole-brain flexibility analysis finds a significant higher neural flexibility for generating creative ideas compared to non-creative ideas. C) This effect is preserved even in a null temporal model, where order of layers are randomized, to control for any temporal dependencies.

Individual Differences – Whole Brain

| | AU_ Flu | AU_ Cre | CC_ Flu | CC_ Cre | Flex AU_Gen | Flex CC_Gen | Flex AU_Eval | Flex CC_Eval |
|---|---|---|---|---|---|---|---|---|
| AU_Flu | - | -.04 | .15 | -.08 | -.17 | -.22 | -.20 | -.35 |
| AU_Cre | | - | .14 | .37 | -.28 | .11 | .06 | .25 |
| CC_Flu | | | - | .21 | -.14 | -.08 | -.12 | .02 |
| CC_Cre | | | | - | .10 | -.02 | .28 | .45 |
| Flex AU_Gen | | | | | - | .24 | .36 | .11 |
| Flex CC_Gen | | | | | | - | .09 | .10 |
| Flex AU_Eval | | | | | | | - | .28 |
| Flex CC_Eval | | | | | | | | - |

**Table 1.** Correlations between behavioral (Flu/Cre) and neural flexibility (Flex) measures. Overall, positive relations between whole-brain flexibility during evaluation (Eval) and CC, and a negative relation flexibility during generation (Gen) and AU.

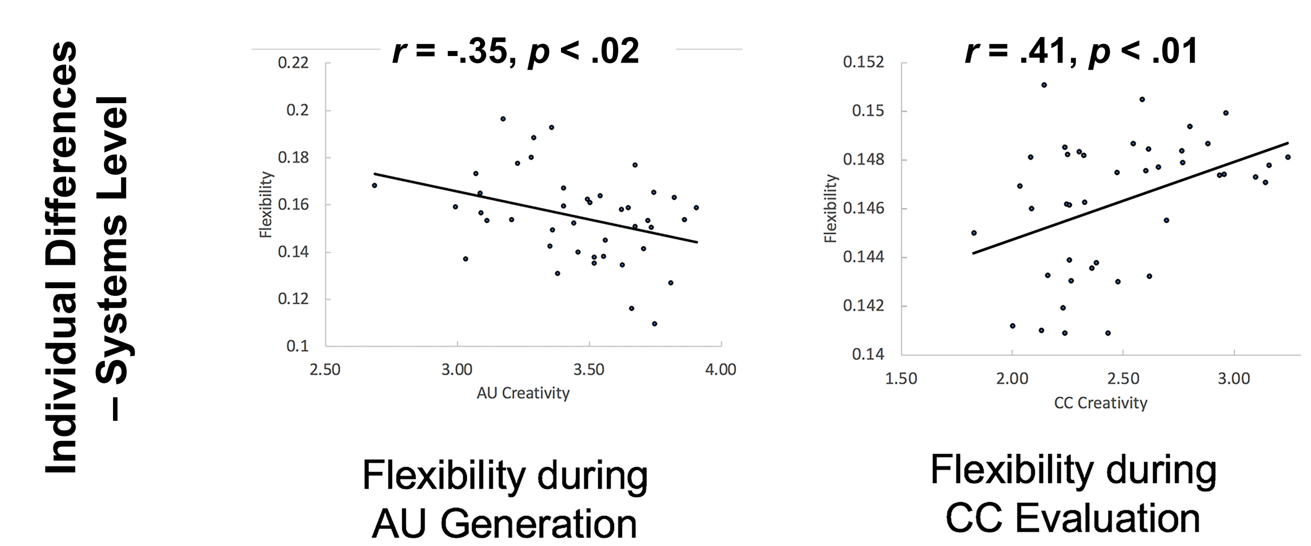


**Fig. 6.** Relation between neural flexibility of the DMN-B system, generating creative ideas, and evaluating non-creative ideas.

## Conclusions

We conduct, for the first time, a within-subject generation-evaluation imaging study of divergent thinking.

We find that generating creative ideas led to significantly higher neural flexible reconfiguration than generating non-creative ideas.

Evaluating creative and non-creative ideas led to similar levels of neural flexible reconfiguration.

Such differences are attributed to different flexible reconfiguration patterns across different neural systems, such as a more/less stable DMN in generating/evaluating creative/non-creative ideas.

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