nature portfolio

Peer Review File

Brainstorming: Interbrain coupling in groups forms the basis of group creativity.

Corresponding Author: Dr Hadas Pick

Version 0:

Reviewer comments:

Reviewer #1

(Remarks to the Author)
The paper explores the influence of group dynamics on creativity, focusing on the interplay between herding behavior and independent thinking (a more flexible thinking) within groups during the performance of creativity tasks. Participants engaged in two divergent thinking tasks within groups of four, while their neural activity was measured. Results showed higher interbrain coupling, particularly in the DLPFC, during creativity tasks compared to pseudo-groups, indicating increased neural synchronization in real groups. Additionally, the study found that interbrain coupling in the IFG, negatively correlated with creativity, while coupling in the DLPFC positively correlated with creativity.
I thoroughly enjoyed reading this paper, it is well-written, and covered a topic that is of great interest.

I have a few comments:

Although the authors have proposed hypotheses based on existing literature and previous studies exploring the relationship between interbrain coupling and creativity, I am curious about the absence of hypotheses concerning regions associated with the Default Mode Network (DMN), a network well-documented in the literature on creativity, as well as the Executive Control Network (ECN).

Furthermore, I believe it would enrich the discussion to explore the potential roles of the IFG and DLPFC in creativity by integrating existing literature and theoretical frameworks with the findings reported here. For instance, the authors could elucidate how their results contribute to our understanding of the involvement of IFG or DLPFC in creativity by connecting the individual-level observations described in the literature with the group dynamics revealed in this study.

The authors did not explicitly explore the creative abilities of each individual within the groups. However, individual creativity could indeed influence the co-activation between brain regions, particularly in the context of group interactions. Individuals with higher levels of creativity might exhibit more pronounced activation in brain regions associated with flexible thinking, such as the DLPFC, during group creativity tasks. Conversely, individuals with lower levels of creativity might show stronger activation in regions associated with herding behavior, such as the IFG. Acknowledging the potential impact of individual creativity on the observed results could offer valuable insights into the interpretation of the findings. If individual creativity was not evaluated, considering this aspect in the discussion or limitation section would be beneficial.

In relation to the previous point, I believe that addressing potential alternative explanations for the observed patterns, such as the influence of individual differences in cognitive abilities, could strengthen the discussion. This would contribute to a more comprehensive understanding of the findings and their implications.

The caption of Figure 9 refers to Clusters 1 to 9, but it is unclear what these clusters represent and where they can be identified in the figure. Additionally, it is unclear which channels correspond to the 24 channels mentioned in the caption.

Providing descriptive statistics from the creativity tasks, such as the mean number of responses for each group, would offer valuable context for interpreting the results, particularly given the short time provided for task performance. Additionally, it would enable a better understanding of the variability of responses within and across groups.

In the methods section, the authors claim ´For each dyad of participants in each group, we calculated the interbrain coupling measure for each combination of homologous regions´. Does it mean that the interbrain coupling is evaluated for all possible pairs of participants within each group, resulting in multiple (or 6) interbrain coupling values per group? Did the authors use the mean of these values? Please clarify.

In the methods section, the authors state, "For each dyad of participants in each group, we calculated the interbrain coupling measure for each combination of homologous regions." Does it imply that the interbrain coupling was assessed for all possible pairs of participants within each group, resulting in multiple (or six) interbrain coupling values per group? It is unclear whether the authors used the mean of the values calculated for each of these pair of participants. Please clarify.

Reviewer #2

(Remarks to the Author)
In this manuscript，the authors made an investigation of the neural mechanics of four member group creativity by using fNIRS hyperscanning. The AUT and EGG task were both used to estimate two types group dynamics of creativity including mindsets of flexibility and herding. The results showed interbrain coupling in the dlPFC associated with flexibility was positively predicted group creativity and in the IFG associated with imitation was negatively predicted. The study tried to explore the neural underpinnings of group dynamics. However, there are still some concerns needed to be revised.
1.The authors selected the AUT and EGG tasks as divergent creative tasks to measure group creativity. Although there are differences between these tasks, the authors used the sum of the total creativity scores on both tasks to represent group creativity, without sufficient literature support. It is important to include convincing and compelling reasons for measuring group creativity in this way.
2.The authors describe the function of dlFPC based on previous studies on Page 3, paragraph 3 from line72. It is suggested that authors should make comments on these studies and clarify the relevance to the present study. What's more, on the 30th reference, it is stated that 'Contrary to previous studies, we did not find that cathodal stimulation increased the novelty of participants' responses', which seems to differ from the authors' statement on Page 3, line 76. The authors should check this supported literature and consider improving the logic of this paragraph.
3. The authors found that the right IFG was associated with herding instead of the left IFG. Further corresponding explanation should be added up to reveal some relative mechanism.
4.In the measures part, the authors chose the frequency range of 0.015 to 0.15 Hz. This processing should be supported by previous research or neural results.

Author Rebuttal letter:

Reviewer #1 (Remarks to the Author):

The paper explores the influence of group dynamics on creativity, focusing on the interplay between herding behavior and independent thinking (a more flexible thinking) within groups during the performance of creativity tasks. Participants engaged in two divergent thinking tasks within groups of four, while their neural activity was measured. Results showed higher interbrain coupling, particularly in the DLPFC, during creativity tasks compared to pseudo-groups, indicating increased neural synchronization in real groups. Additionally, the study found that interbrain coupling in the IFG, negatively correlated with creativity, while coupling in the DLPFC positively correlated with creativity.
I thoroughly enjoyed reading this paper, it is well-written, and covered a topic that is of great interest.
I have a few comments:
Although the authors have proposed hypotheses based on existing literature and previous studies exploring the relationship between interbrain coupling and creativity, I am curious about the absence of hypotheses concerning regions associated with the Default Mode Network (DMN), a network well-documented in the literature on creativity, as well as the Executive Control Network (ECN).
We thank the reviewer for this important comment. As suggested, we now explain in the Introduction section that neuroimaging studies on creativity have repeatedly found that while Default Mode Network (DMN) that includes regions such as the medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), and temporo-parietal junction (TPJ), mediate the generation phase of creative thinking (Marron et al., 2018; Mayseless et al., 2015; Zhu et al., 2017; Raichle et al., 2001; KÃ¼hn et al., 2014), the Executive Control Network (ECN) is thought to play a critical role in the cognitive processes of evaluating, shifting and selecting ideas (Beaty and Kennett, 2023). We also indicate that the IFG possibly assesses ideas within the context of social norms (Kleinmintz et al., 2019), significantly influencing group alignment and imitation within the group .
Furthermore, I believe it would enrich the discussion to explore the potential roles of the IFG and DLPFC in creativity by integrating existing literature and theoretical frameworks with the findings reported here. For instance, the authors could elucidate how their results contribute to our understanding of the involvement of IFG or DLPFC in creativity by connecting the individual-level observations described in the literature with the group dynamics revealed in this study.
As suggested, in the Discussion section, we now elaborate on the neural underpinnings of creativity in both individual and group contexts, focusing on the roles of the IFG and the DLPFC.
For individual creativity, the DMN is essential in generating ideas from long-term memory, while the ECN assists in the evaluation and transition between these ideas. During individual creativity, the

DLPFC is particularly critical, promoting cognitive flexibility necessary for selection and transition between ideas. The Observation-Execution system, prominently involving the IFG, is crucial for evaluating ideas and aligning ideas with internalized norms during individual creativity and externally presented group norms during group creativity. In group settings, DLPFC activity, when coupled across individuals, facilitates a coordinated flexible mindset through interbrain coupling, enhancing collective creativity. However, while interbrain coupling in the IFG supports social coherence, it may also suppress novelty, leading to mimicry rather than innovation. Thus, we hold that optimal group creativity is achieved by balancing interbrain coupling: enhanced DLPFC coupling fosters flexible idea navigation, whereas diminished IFG interbrain coupling reduces conformity, promoting originality and diversity in creative outputs.

The authors did not explicitly explore the creative abilities of each individual within the groups. However, individual creativity could indeed influence the co-activation between brain regions, particularly in the context of group interactions. Individuals with higher levels of creativity might exhibit more pronounced activation in brain regions associated with flexible thinking, such as the DLPFC, during group creativity tasks. Conversely, individuals with lower levels of creativity might show stronger activation in regions associated with herding behavior, such as the IFG. Acknowledging the potential impact of individual creativity on the observed results could offer valuable insights into the interpretation of the findings. If individual creativity was not evaluated, considering this aspect in the discussion or limitation section would be beneficial.

As suggested, we now address the potential impact of individual creativity on the observed results. We originally collected data on individual creativity performance in our sample using the Torrance test of creative thinking. To examine if individual scores predict group performance, in the results section we perform two linear nixed models to predict individual creativity based on group creativity and interbrain coupling, with group ID as random effect. We found no relationship between group and individual creativity. We now report these findings and discuss those findings in the Discussion section.

In relation to the previous point, I believe that addressing potential alternative explanations for the observed patterns, such as the influence of individual differences in cognitive abilities, could strengthen the discussion. This would contribute to a more comprehensive understanding of the findings and their implications.

As suggested, we now offer a general model that integrates group and individual creativity. We explain in the DMN is pivotal in generating ideas by accessing long-term memory, providing a substrate for imaginative thought. Concurrently, the ECN mediates the cognitive processes involved in transitioning between and selecting viable ideas, ensuring a structured approach to creativity. Specifically, the DLPFC plays a critical role in individual creativity by promoting cognitive flexibility, which is essential for the dynamic selection and transition between ideas. This flexibility enables the recombination of existing information into novel configurations.

In group creativity contexts, coupled activity across individuals' DLPFCs, is instrumental in fostering a collective mindset that is both flexible and coordinated, thereby enhancing the creative output of the group. This phenomenon allows for the effective merging of diverse perspectives and ideas. Additionally, the Observation-Execution system, particularly involving the IFG, is integral to the social evaluation of ideas. In individual settings, the IFG aligns creative outputs with internalized norms, while in group settings, it contributes to more imitation and conforming with others.

The caption of Figure 9 refers to Clusters 1 to 9, but it is unclear what these clusters represent and where they can be identified in the figure. Additionally, it is unclear which channels correspond to the 24 channels mentioned in the caption.

We apologize for the confusion. We now clarify that in figure 9a T represents a transmitter and R represents a receiver. We also change the term cluster to T to avoid confusion. Additionally, we clarify that each pairing of a transmitter and a receiver forms a channel, resulting in 12 channels in each hemisphere, represented with black lines in figure 9b.

Providing descriptive statistics from the creativity tasks, such as the mean number of responses for each group, would offer valuable context for interpreting the results, particularly given the short time provided for task performance. Additionally, it would enable a better understanding of the variability of responses within and across groups.

As suggested, descriptive statistics for the creativity tasks are now presented in a table within the Method section.

In the methods section, the authors claim Â´For each dyad of participants in each group, we calculated the interbrain coupling measure for each combination of homologous regionsÂ´. Does it mean that the interbrain coupling is evaluated for all possible pairs of participants within each group, resulting in multiple (or 6) interbrain coupling values per group? Did the authors use the mean of these values? Please clarify.

As suggested, we have provided a more detailed explanation of how we calculated group interbrain coupling. For each ROI in a group of four participants (A, B, C, D), there are six pairs (AB, AC, AD, BC, BD, CD). We computed the Wavelet Transform Coherence (WTC) for each pair. To derive a single measure of interbrain coupling for the group, we then averaged the WTC values across all pairs.

Reviewer #2 (Remarks to the Author):

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1.The authors selected the AUT and EGG tasks as divergent creative tasks to measure group creativity. Although there are differences between these tasks, the authors used the sum of the total creativity scores on both tasks to represent group creativity, without sufficient literature support. It is important to include convincing and compelling reasons for measuring group creativity in this way.
As suggested, we now explain the reasons for combining the scores from the two creativity tasks. We indicate that this decision was influenced by our prior identification of a significant correlation between these tasks, both of which involve divergent thinking (Fahoum et al., 2023).
2.The authors describe the function of dlFPC based on previous studies on Page 3, paragraph 3 from line72. It is suggested that authors should make comments on these studies and clarify the relevance to the present study. Whatâs more, on the 30th reference, it is stated that 'Contrary to previous studies, we did not find that cathodal stimulation increased the novelty of participants' responses', which seems to differ from the authors' statement on Page 3, line 76. The authors should check this supported literature and consider improving the logic of this paragraph.
We apologize for the confusion in citing the references. We have now clarified that while a recent study did not find that cathodal (inhibitory) direct current stimulation (tDCS) of the prefrontal cortex increased the novelty of participants' responses (Kenett et al., 2021), a previous study demonstrated that cathodal tDCS over the left IFG enhanced fluency in a divergent-thinking task that required generating uncommon ideas (Chrysikou et al., 2013). On the other hand, it has been demonstrated that anodal tDCS over the left DLPFC facilitates performance in convergent thinking tasks that require creative problem-solving (Metuki et al., 2012; Zmigrod et al., 2015).
3. The authors found that the right IFG was associated with herding instead of the left IFG. Further corresponding explanation should be added up to reveal some relative mechanism.
As suggested, we now explain in the discussion section that the involvement of the right IFG is consistent with its recognized roles in imitation, coordination, intention coding, and perception-action matching (Wei et al., 2023). Distinctly, interbrain coupling in the left IFG has been associated with verbal synchronization during communicative tasks (Jiang et al., 2012), whereas the right IFG has been linked to non-verbal coordination (Minagawa et al., 2018). This suggests that elevated interbrain coupling in the right IFG may predominantly enhance non-verbal imitation of ideas which could detrimentally impact group creativity.
4.In the measures part, the authors chose the frequency range of 0.015 to 0.15 Hz. This processing should be supported by previous research or neural results.
As suggested, we now explain that we selected this frequency band because it falls outside the typical frequencies associated with heart rate (around 1â2 Hz) and breathing (around 0.2â0.3 Hz), which are common sources of noise in fNIRS data (Scholkmann et al., 2014)

Version 1:

Reviewer comments:

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Thank you very much to the authors for addressing all my suggestions and comments. The article was already clear, good, and interesting, and the modifications have further improved it. I only have one more comment regarding the analysis of the impact of individual creativity on group creativity. I wonder why the authors used individual creativity as the dependent variable in the LME models, instead of using group creativity as the dependent variable. If the goal is to evaluate the impact of individual creativity on the group, isn't it a better approach to do it the other way around?

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The authors have made responses to the comments and revised the manuscript with convincing evidence. The revised manuscript has enhanced the overall quality of the article. The organization, and academic soundness have been improved. The current version effectively presents the argument and supports it with appropriate evidence. Given the improvements made, the manuscript is now considered suitable to be accepted.

Author Rebuttal letter:

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We thank the reviewer for this important comment. Given that group creativity is constant within groups, we recognized that using LME with group creativity as the dependent variable could lead to convergence issues due to the lack of within-group variance. We agree with the reviewer's suggestion and have revised our approach. Instead of using LME, we now calculate the mean of individual creativity for each group and use this to predict group creativity in a linear regression model.

Reviewer #2 (Remarks to the Author):

The authors have made responses to the comments and revised the manuscript with convincing evidence. The revised manuscript has enhanced the overall quality of the article. The organization, and academic soundness have been improved. The current version effectively presents the argument and supports it with appropriate evidence. Given the improvements made, the manuscript is now considered suitable to be accepted.