EEG correlates of insight

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Insight is described as a sudden solution of a problem and is contrasted with analytical, step by step approach.





Wallace's theory

- 1. Preparation (accumulation of necessary information).
- 2. Incubation (a period when conscious attention is not directed to solving a problem).
- 3. Insight (a creative idea flashes in the mind).
- 4. Verification (a creative idea undergoes verification).

The study of creativity in the laboratory

The study of creativity and insight in the laboratory is fraught with difficulties. It is unlikely that subjects will be able to find a creative solution and experience insight at a strictly defined time. "The prospect of looking for creativity in the brain must seem like trying to nail jelly to the wall" (Dietrich & Kanso, 2010).



Stage 2: Incubation

- Empirical evidence generally confirms that incubation period indeed contributes to the emergence of a creative idea (Dodds et al., 2003; Sio & Ormerod, 2009).
- ➢ It is not clear, however, why and how this happens.
- One of the possible ways to understand this is to study brain activity during the incubation period.





Default mode network (DMN)

Task-negative and task-positive networks



DMN

CEN

Networks and creativity

- Structural MRI shows that psychometric measures of creativity correlate with DMN volume (Jung et al., 2010; Kühn etal., 2013).
- ➢ However, mind-wandering is accompanied not only by activation of the DMN, but also of networks that control attention (Smallwood, Schooler, 2006; Smallwood et al., 2009).
- Insight is the culmination of a series of brain states and processes that operate on different time-scales (Kounios & Beeman, 2009).

Networks and creativity

- Creativity could not be explained by any single mental process or brain area (Dietrich & Kanso, 2010).
- DMN can be considered one of, but not the only network related to creativity.

Stage 3: Insight

Hypotheses:

- 1. The right hemisphere, in particular, the right superior temporal gyrus plays a special role in insight (Bowden, Jung-Beeman, 2003; Jung-Beeman et al., 2004).
- An increase of alpha power is expected as a correlate of decreased activity of consciousness (Kounios et al., 2008; Sandkuhler & Bhattacharya, 2008).

Hypothesis 1: Right hemisphere

- Several studies do indicate the special role of the right superior temporal gyrus (STG) in the occurrence of insight (Jung-Beeman et al., 2004; Kounios et al., 2008; Qiu et al., 2006; Sandkuhler & Bhattacharya, 2008).
- But even more studies do not confirm this hypothesis (Danko et al., 2003; Kounios et al., 2006; Lang et al., 2006; Lavric et al., 2000; Mai et al., 2004; Qiu et al., 2008a, 2008b).
- ➢ Some studies indicate the special role of the left STG, both in the occurrence of insight and in other stages of creative thinking (Qiu et al., 2008).

Hypothesis 2: Alpha activity

- Some studies of insight find an increase of alpha power in the frontal, parietal, and temporal regions (Kounios et al., 2008; Sandkuhler & Bhattacharya, 2008), which is interpreted as evidence of decreased activity of consciousness.
- However, this contradicts fMRI data indicating activation of the frontal and temporoparietal regions during insight (Dietrich & Kanso, 2010).
- In other studies, insight-related decrease in alpha and increase in delta, theta, beta, and gamma power is described (Danko et al., 2003; Jung-Beeman et al., 2004; Kounios et al., 2006).

Summary of evidence

- One of the few well-reproduced findings in the study of insight is the involvement of the STG (Jung-Beeman et al., 2004; Kounios et al., 2008; Qiu et al., 2006, 2008; Sandkuhler & Bhattacharya, 2008), but this refers to only one experimental paradigm - the remote associations test (Mednick & Mednick, 1959, 1962).
- Insight is only the culmination of a series of brain states and processes that operate on different time scales (Kounios & Jung-Beeman, 2009).
- Accordingly, creativity and insight are not uniquely associated with any one mental process, or brain area (Dietrich, Kanso, 2010).

Study aims

- Firstly, we aimed to identify the relationship between the patterns of connectivity of resting state networks during the incubation period with the success of solving problems in the post-incubation period.
- Secondly, we aimed to identify the dynamics of brain activity in the period preceding and accompanying the occurrence of insight, using the analysis of source-level EEG data.

Sample: N = 63 (31 females, mean age 26.3, SD 10.3, all right-handed).

Task: Remote association test (Mednick & Mednick, 1959, 1962; Valueva & Belova, 2011):

a triple of words, to which one needs to find the fourth word, forming a stable phrase with each of the three words.

3 stages - preparatory (first attempt), incubation, and post-incubation (second attempt). As an incubation task, a five-minute audio recording of an excerpt from a sci-fi book was used.

EEG recording – 127 electrodes, sampling rate 1000 Hz, Cz as the reference. EEG data were recomputed to the average reference offline and artifact corrected using independent component analysis in the EEGlab. Individual position of each electrode was measured by FASTRAK (Polhemus).

1. Effect of incubation. Pipeline of EEG data analysis.



Seeds: the DMN (four seeds), the central executive network (two seeds), and the salience network (two seeds).

Percent of solved problems before and after incubation



Connectivity in the successful and unsuccessful groups





Discussion of connectivity results

- The main function of the central executive network is to sustain attention to the task in hand.
- During the incubation period, the task in hand was to listen the distracting text unrelated to unsolved problems.
- Higher activity of the central executive network in this period may only disrupt the search of solution, which indeed is observed in the unsuccessful group.
- The salience network, participates in the switching attention from the external to the internal world and in catching most salient stimuli in the stream of consciousness.
- Higher activity of this network in the successful group shows that these subjects did not cease the search of solution during the incubation.

Discussion of connectivity results

- The effect was found in the left motor cortex, which should be active when the subject finds the solution and prepares to press the spacebar with her right hand.
- The fact that this area in successful subjects is under higher influence of the salience network indicates a state of constant preparedness to report the result.
- The effect was found in the theta frequency band, which is associated with emotion and contextual memory (Klimesch, 1999; Knyazev, 2007).
- Emotional stress and incessant search in memory distinguish successful from unsuccessful subjects

2. Insight versus analytical problem solving

Current source density estimates

- ➢ Within-subject approach
- Sixteen-second EEG epoch preceding the spacebar pressing was divided into 8 two-second epochs and submitted to source localization using eLORETA.
- The insight-analytic comparison was made for each of the eight epochs using a nonparametric analog of the paired-samples t-tests.
- In addition, both variants of problem solving were compared with trails in which the problem was not solved.

2. Insight versus analytical problem solving Connectivity estimates

- Lagged phase synchronization was used for connectivity estimation.
- Regions of interest (ROIs): DMN hubs (MPFC, PCC, left and right parietal cortex) plus 7 clusters in which data analysis revealed significant effects when comparing insight and analytical solutions.
- For each ROI, the data were averaged within a sphere centered at the corresponding point with a diameter of 10 mm

Insight: Behavioral results

- On average, 143 correct solutions were marked as insight and 104 as analytical.
- Among the wrong decisions, 80 were marked as insight and 171 as analytical.
- The average time to solve the problem was significantly longer for analytical than for insightful solutions (t = 2.26, p = 0.026).

Difference between the number of correct and incorrect decisions was significantly higher when the solution was described as insight (t = 4.58, p < 0.001).



EEG spectral power: Insight versus lack of solution



EEG spectral power: Insight versus analytical



EEG connectivity: Insight versus analytical



Discussion

- Brain activity in analytical trials was minimally different from that in unsuccessful trials. This suggests that in most unsuccessful trials, subjects used an analytical strategy to find a solution.
- Most of incorrectly solved problems were also solved using analytical method.
- Since analytical solutions on average require more time, one might think that in many cases it was either not found (unsuccessful trials) or announced that the solution was ready without a sufficient check of its correctness (incorrectly solved problems).

Discussion

- Brain activity accompanying insight was significantly different from that in unsuccessful and analytical trials.
- Many effects were detected in the delta range, which is associated with motivational processes and with attention to motivationally relevant stimuli.
- In addition, delta activity is traditionally associated with a decrease in conscious perception and correlates with processes occurring at the subconscious level (Knyazev, 2007, 2012).
 Effects in the delta frequency range have also been described in other studies of insight (Danko et al., 2003).

Discussion

- The earliest insight-related effect is increased delta activity in the PCC (a DMN hub) and reduced connectivity between the left insula and the left STG in theta frequency range. This combination can be interpreted as a reduced search in memory at the conscious level and the initiation of the search at the subconscious level.
- The insight itself is probably associated with high-frequency activity in semantic (Wernicke zone and inferior temporal gyrus) and emotional (insula) cortical areas at 10 seconds before the spacebar pressing.

Conclusion

- ➢ Insight solutions were faster on average and correct in more cases.
- Brain activity during analytical solving was minimally different from that in the absence of a solution, which suggests the presence of an analytical method in the latter case also.
- At early stages, differences between insight and analytical solutions are detected in the delta frequency range in DMN and executive control network.
- Brain activity, presumably associated with the occurrence of insight, was detected in beta and gamma ranges in cortical areas involved in semantic and emotional processing.
- ➢ In general, our results support the view that incubation and insight are complex multistage processes, which at different stages involve activity of both the DMN and the attention networks.





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Thank you for attention