NeuroImage xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Generating original ideas: The neural underpinning of originality

Naama Mayseless [a,*], Ayelet Eran [b,1], Simone G. Shamay-Tsoory [a,1]

[a] Department of Psychology, University of Haifa, Haifa 31905, Israel
[b] Department of Radiology, Rambam Health Care Campus, Haifa, Israel

ARTICLE INFO

Article history:
Received 10 March 2015
Accepted 13 May 2015
Available online xxxx

Keywords:
Creativity
Originality
fMRI
Prefrontal cortex
Anterior cingulate cortex

ABSTRACT

One of the key aspects of creativity is the ability to produce original ideas. Originality is defined in terms of the novelty and rarity of an idea and is measured by the infrequency of the idea compared to other ideas. In the current study we focused on divergent thinking (DT) – the ability to produce many alternate ideas – and assessed the neural pathways associated with originality. Considering that generation of original ideas involves both the ability to generate new associations and the ability to overcome automatic common responses, we hypothesized that originality would be associated with activations in regions related to associative thinking, including areas of the default mode network (DMN) such as medial prefrontal areas, as well as with areas involved in cognitive control and inhibition. Thirty participants were scanned while performing a DT task that required the generation of original uses for common objects. The results indicate that the ability to produce original ideas is mediated by activity in several regions that are part of the DMN including the medial prefrontal cortex (mPFC) and the posterior cingulate cortex (PCC). Furthermore, individuals who are more original exhibited enhanced activation in the ventral anterior cingulate cortex (vACC), which was also positively coupled with activity in the left occipital–temporal area. These results are in line with the dual model of creativity, according to which original ideas are a product of the interaction between a system that generates ideas and a control system that evaluates these ideas.

Introduction

Creativity is the capacity that allows us to create art, develop new technologies and conduct new cutting edge research. As such, it has been studied in a variety of ways, including numerous studies that have focused on understanding the individual characteristics and developmental trajectories of creative geniuses (Csikszentmihalyi, 1996; Mumford and Gustafson, 1988; Simonton, 2003) such as great scientists, inventors or famous artists. Despite the fact that creativity is often thought of in terms of these creative geniuses, it is a property shared by all humans and is expressed in our ability to produce ideas that are on one hand novel and new and on the other hand appropriate and useful (Stein, 1953; Sternberg and Lubart, 1999).

In line with this conception, a distinction has been made between "little c" and "big C" creativity (Gardner, 1993). While "big C" creativity refers to great works of art and major discoveries, "little c" creativity refers to the everyday acts of creativity that allow us to solve everyday problems and adapt to the ever-changing environment (Runco, 2004). The study of "little c" creativity is thus important as it allows us to better understand our ability to create new ideas during daily tasks and it provides a window into the processes that promote "big C" (Ward and Kolomyts, 2010). One way used to measure creativity, specifically "little c" creativity, is through divergent thinking (DT) tasks. DT requires the formulation of multiple possible answers to a problem that has more than one possible solution and allows for the generation of diverse new ideas. Considering that measures of DT may predict creative achievement (Kim, 2008), they are considered beneficial for the investigation of creativity and originality (Takeuchi et al., 2012).

Creativity is often seen as comprising both a measure of the quantity of ideas (fluency of ideas) and a measure of their quality (originality). As such, originality is a key feature of creativity (Runco and Jaeger, 2012). The originality of an idea is based on its statistical infrequency, which represents the uniqueness of the response (Wilson et al., 1953). Originality is a vital but insufficient condition for creativity as appropriateness is also required. In order to be original, an individual must at the same time inhibit more common automatic ideas as well as be able to move flexibly to alternate associations that produce remote or indirect associations (Mednick, 1962; Wilson et al., 1953). Thus, it is expected that the brain network that mediates originality may be involved in connecting between remotely related associations as well as in inhibiting more common unoriginal associations.

Although previous studies have reported a lack of consistency in brain areas related to creativity (Arden et al., 2010; Dietrich and Kanso, 2010; Sawyer, 2011), one network that has repeatedly been

* Corresponding author. Fax: +972 4 8240966.
E-mail addresses: naama27@gmail.com (N. Mayseless), a_eran@rambam.health.gov.il (A. Eran), sshamay@psy.haifa.ac.il (S.G. Shamay-Tsoory).
[1] Tel.: +972 4 8288778; fax: +972 4 8240966.

http://dx.doi.org/10.1016/j.neuroimage.2015.05.030
1053-8119/

found to take part in creativity is the default mode network (DMN; Gusnard and Raichle, 2001; Jung et al., 2013; Raichle and Snyder, 2007). The DMN is a network of brain regions which is detected using functional connectivity MRI during task-free times. Activity in the DMN has been reported to increase when there is no external task and decrease in activation in the presence of an external task (Raichle et al., 2001). Regions within the DMN have been consistently reported to be activated in tasks of creativity (Beaty et al., 2014; Jung et al., 2013). These regions include the medial prefrontal cortex (mPFC), the posterior cingulate cortex (PCC) and bilateral inferior parietal lobes including temporo-parietal areas (Fox et al., 2005; Gusnard and Raichle, 2001). Specifically, the mPFC has been implicated in a number of high-level functions, including decision-making (Fleck et al., 2006), association-based predictions (Bar, 2007, 2011), executive control and monitoring conflicts (Alvarez and Emory, 2006; Badre and Wagner, 2004). As such, it can serve to generate original ideas by inhibiting automatic common ideas while at the same time allowing for the flexibility needed in order to move between associations and form novel connections. In addition to the mPFC, temporo-parietal areas have also been reported as taking part in response to inhibition and competition, which can serve to generate more remote associations (Garavan et al., 1999; Menon et al., 2001; Smith et al., 2006). Binder et al. (2009) proposed that temporo-parietal areas play a role in complex information integration and knowledge retrieval, which are important features in creative associative thinking. Furthermore, temporo-parietal as well as posterior cingulate cortex (PCC) areas have been proposed to be involved in memory retrieval (Ciaramelli et al., 2008; Sugiura et al., 2005) an important part of creative thinking, reflecting bottom-up attentional processes (Cabeza, 2008). Therefore, the DMN (including the mPFC, PCC and temporo-parietal areas) can serve to inhibit the retrieval of more commonplace ideas to allow for more remote associations that can lead to greater originality (also see Fink et al., 2010). These findings taken together suggest that creativity can be mediated by a network involving areas of the DMN that supports the generation of unique and novel associative ideas while inhibiting those that are more mundane.

In direct support of the DMN and its components in creativity, Howard-Jones et al. (2005) found that creative story generation was associated with bilateral mPFC and right middle occipital activation and lower activity in the right inferior parietal lobe. Furthermore, increased resting functional connectivity in association with creative ability has been reported between areas of the DMN including the mPFC and the middle temporal gyrus (Wei et al., 2014) as well as between the mPFC and the PCC (Takeuchi et al., 2012). In addition, Beaty et al. (2014) found that highly creative individuals exhibit increased functional connectivity between bilateral inferior prefrontal cortex and areas in the DMN (mPFC, PCC and IPL). In line with these findings, areas in the DMN including the PCC and temporo-parietal cortex have been linked to mind wandering (Christoff et al., 2009), which has been shown to facilitate creativity (Baird et al., 2012). In addition, Ellamil et al. (2012) found that creative generation of ideas activated areas including the inferior and superior parietal lobule, while Fink et al. (2010) reported that generation of ideas is associated with activations in the left parieto-temporal brain regions.

So far, only a few studies have focused on originality as part of the neuroscientific investigation of creativity. Chávez-Eakle et al. (2007) found that cerebral blood flow (CBF) in the anterior region in the rostral PFC (ventomedial PFC, BA 10) was associated with the originality of responses as measured by DT tasks. Others have found that original idea production is associated with increases in alpha EEG power, most noticeably in centro-parietal cortices (Fink and Neubauer, 2006) especially in the right hemisphere (Grabner et al., 2007). In a recent fMRI investigation, Benedek et al. (2014) found significant activation in the left inferior parietal area when new ideas were generated (compared to old ideas). With respect to originality levels, Kowatari et al. (2009) reported that activations in parietal cortices predicted lower levels of originality in a task of design creation.

In accordance with the neuroimaging findings of a frontal temporo-parietal network that mediates originality, Shamay-Tsoory et al. (2011) reported that patients with mPFC lesions exhibited lower originality compared to a group of healthy controls, whereas patients with inferior frontal lesions and those with parietal–temporal lesions performed comparably and even better than healthy controls.

Taken together, the above findings indicate that regions which are part of the DMN such as the mPFC, PCC and the inferior parietal lobule (angular gyrus and supramarginal gyrus) are key regions in a network that mediates the generation of creative original ideas. Yet it is unclear to what extent each area contributes to originality and what process leads to more original ideas.

The aim of the present study was to investigate the mechanisms underlying the generation of original ideas. Furthermore, the current study sought to identify brain regions whose activity predicts increased levels of originality. To assess originality during scanning, we modified the classic Alternate Uses Task (AUT) in order to examine the ability to generate original ideas.

We hypothesized that originality would be associated with greater activity regions of the DMN (in the mPFC as well as in temporo-parietal brain regions, including the temporo-parietal junction and the PCC). Furthermore, we predicted that task-related connectivity between areas in this network would be positively associated with individual originality levels.

Method

Participants

Thirty healthy right-handed volunteers (mean age 25.7, SD = 2.3, 15 female) participated in the study. Two participants were excluded due to excessive movement and one left the study voluntarily. In addition, the responses of two participants were not recorded due to technical difficulty with the recording device. All participants had normal or corrected-to-normal vision, all provided written informed consent and all were paid for their participation. The consent and protocol were approved by the Helsinki Committee of Rambam Health Care Campus in Haifa, Israel. The average intelligence level of the participants as measured by the Shipley Intelligence Scale score was within the normal range ($\geq$40). There were no significant differences between males and females in the Shipley scores ($t = 0.48$, $p = 0.63$) and no correlation with originality ($r = 0.08$, $p = 0.68$).

DT task

A modified version of the AUT (Guilford et al., 1978) was designed to allow for the measurement of originality in the fMRI experiment. The task was based on the paper version of the AUT, in which an everyday object is presented and participants are asked to provide possible alternative uses for this object that are different from the everyday common use. In the modified computerized version used in the current study, participants were presented with the object and were instructed to think of one possible use for the object. The uses were required to be different from the everyday common use, and participants were asked to think of an original use, with emphasis on it being novel and unique. The modified computerized version was tested in a pilot study in order to verify that originality levels did not differ in the two versions (the customary paper version and the modified one). The pilot study was conducted among fifty healthy right-handed volunteers (mean age 23.61 SD = 2.38). Participants completed both the paper version of the AUT and the modified computerized version, which were counterbalanced. The paper version consisted of five objects with a time limit of ten minutes for all five objects. The computerized version consisted of five objects that were different from those in the paper version. In the computerized version, each object was presented twice (separated into two blocks, once in each block). Participants were

Please cite this article as: Mayseless, N., et al., Generating original ideas: The neural underpinning of originality, NeuroImage (2015), http://dx.doi.org/10.1016/j.neuroimage.2015.05.030