Behavioural Brain Research 214 (2010) 143–156

Contents lists available at ScienceDirect

Behavioural Brain Research

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

Review

Neuroimaging creativity: A psychometric view

Rosalind Arden[a,c], Robert S. Chavez[b], Rachael Grazioplene[b], Rex E. Jung[a,b,*]

[a] *Department of Neurosurgery, MSC10 5615, 1 University of New Mexico Health Sciences Center, Albuquerque, NM 87131-0001, United States*
[b] *The Mind Research Network, 1101 Yale Boulevard NE, Albuquerque, NM 87106, United States*
[c] *King's College London, Social, Genetic, Developmental & Psychiatry Centre, De Crespigny Park, London SE5 8AF, England, United Kingdom*

A R T I C L E I N F O

Article history:
Received 17 February 2010
Received in revised form 6 May 2010
Accepted 10 May 2010
Available online 19 May 2010

Keywords:
Creativity
Divergent thinking
Convergent thinking
Insight
Intelligence
Neuroimaging
Psychometrics
EEG, electroencephalography
fMRI, functional magnetic resonance imaging
DTI, diffusion tensor imaging
MRS, magnetic resonance spectroscopy
NIRS, near infrared spectroscopy
PET, positron emission tomography
Phase
Power
Coherence
Synchronization

A B S T R A C T

Many studies of creative cognition with a neuroimaging component now exist; what do they say about where and how creativity arises in the brain? We reviewed 45 brain-imaging studies of creative cognition. We found little clear evidence of overlap in their results. Nearly as many different tests were used as there were studies; this test diversity makes it impossible to interpret the different findings across studies with any confidence. Our conclusion is that creativity research would benefit from psychometrically informed revision, and the addition of neuroimaging methods designed to provide greater spatial localization of function. Without such revision in the behavioral measures and study designs, it is hard to see the benefit of imaging. We set out eight suggestions in a manifesto for taking creativity research forward.

Contents

* Corresponding author at: Department of Neurosurgery, MSC10 5615, 1 University of New Mexico Health Sciences Center, Albuquerque, NM 87131-0001, United States. Tel.: +1 505 918 0066; fax: +1 505 272 8006.
E-mail address: rjung@mrn.org (R.E. Jung).

0166-4328/$ – see front matter
doi:10.1016/j.bbr.2010.05.015

1. Introduction

What counts as creativity? How do you measure it? Can we decipher its neural signature in the brain? These are the central questions in the neuroscience of creativity. In this report we review empirical publications on creative cognition that have an imaging component; then we suggest future directions for the field.

How do you test for creativity? In the oldest scientific journal, an eyewitness described his encounter with the young Wolfgang Amadeus Mozart thus: "I said to the boy, that I should be glad to hear an extemporary *Love Song*, ... He then played a symphony which might correspond with an air composed to the single word *Affetto* [('con Affetto' means 'with love')]. It had a first and second part, which together with the symphonies, was of the length that opera songs generally last ..." [1]. The writer, who was greatly impressed by the young Mozart, reported to the Royal Society that, charmingly, between *de novo* compositions, the young boy would not desist from playing with his cat, nor from running around with a stick between his legs. Even prodigies like to play horse. Mozart's musical mastery was characterized by accuracy and fluency in intellectually challenging sight-reading, but his capacity to innovate, evaluated by his older contemporary, Daines Barrington, defines him as a creative genius.

It is much easier to identify creative people or work in hindsight than to capture exactly what we mean by creativity in a semantic net. Are luminous creative geniuses like Mozart at the far end of a normal distribution? Or is creativity qualitatively heterogeneous? Is the 'juice' of creativity that ran in Leonardo da Vinci's veins the same juice that fuelled Marie Curie? These are the same kinds of questions that have been asked about many phenomena in the history of science; even those that are apparently lower order and more simple. Our primeval ancestors could manipulate heat, but Brownian motion (which describes heat kinetically) was not discovered until 1827 (and then not by a physicist but by a botanist). It is not surprising that it is taking decades to characterize and measure creativity. Given the heterogeneity of creative expression, and the relative youth of the field, it is perhaps to be expected that there is little consistency in the findings that we reviewed for this article.

Creativity in humans is a complex behavior involving utility, beauty, and innovation (see for working definitions [2,3]. The want of an exact specification is not an important impediment. 'Species' and 'genes' are the bread and butter of biologists and geneticists yet there is a precise definition of neither; refinements to complex constructs often emerge over time. How is creative cognition measured currently?

Researchers generally use two broad classes of creative cognition tasks: 'divergent' and 'convergent'. Divergent thinking tests are instruments that have been designed to be open-ended (to afford multiple correct answers, such as 'describe what would happen if rain was green') [4]. Convergent tests or items are those that have a single correct answer (such as 'which solar planet is closest to Earth in density?') A serious challenge to operationalising creative cognition is that tests with a convergent answer tend to measure intelligence, whereas tests with an open (subjective or rater-scored) answer tend to have lower reliability and validity. There is evidence that peer ratings on some creative cognition tasks show reasonably high inter-rater agreement which increases the usefulness of the tests [5].

In the work we have read, no creativity researcher claims that either a single scale or test battery circumscribes the construct adequately. As has been said forcefully [6], the manifestations and causes of creative cognition are plural. There is insufficient evidence yet to say whether or not creative cognition is psychometrically unitary as is the case with the *g* factor in intelligence [7]. Currently used creative cognition measures depend on intuitions about processes (such as fluency of answer production, finding correct solutions in a problem-space, or finding open solutions in a problem-space) that seem suitable candidates for exploration. Since Joy Paul Guilford gave his Presidential Address to the American Psychological Association in 1950 [4], there has been a keen appreciation of the need for psychometric measurement of creative cognition.

Here we summarize recent empirical reports of creative cognition that include a neuroimaging element. We identified published reports by searching abstracts in Web of Science and other databases that included the words creativity, divergent thinking and (using Boolean operators) fMRI, MRI, imaging, EEG, PET, MEG, SPECT, rCBF, ASL, DTI and NIRS. We did not include studies from contiguous and relevant areas such as 'insight' or 'innovation' unless they also included creativity explicitly because we aimed to focus narrowly on the central construct. We culled only non-empirical studies and those empirical studies carried out in patient populations. This approach carries with it the distinct advantages of simplicity, limitations upon the need for human choice in what is "in" or "out" of consideration, reproducibility, and thus generalizability to future inquiries.

2. Neuroimaging

Brain-imaging research affords various ways of seeing behavior instantiated in electrical signals, blood oxygen levels, brain structure, cerebral blood flow or in metabolite concentrations. Creativity researchers deploy a family of imaging modalities. These include diffusion tensor imaging (DTI), electroencephalography (EEG), functional magnetic resonance imaging (fMRI), magnetic resonance spectroscopy (MRS), near infrared optical imaging, positron emission tomography (PET), regional cerebral blood flow (rCBF) and structural magnetic resonance imaging (sMRI). These different ways of seeing fall into two groups: those that investigate function (how does the brain look when it is working on a task?), and those that explore structure (does the task have neuroanatomical correlates?).

3. Functional imaging

3.1. EEG studies

EEG experiments use of a set of electrodes placed on the scalp in a pattern according to standardized templates such as the international 10-20 system (see for description [8], p. 27–30). The outcome of an EEG recording is given as the voltage difference between electrode sites plotted over time (for an excellent exposition on EEG see