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Current Opinion in Behavioral Sciences

Where in the brain is creativity: a brief account of a wild-goose chase

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The neuroscientific study of creativity is stuck and lost. Having perseverated on a paradigm — divergent thinking — that is theoretically incoherent, the field has neither produced intelligible data on the brain mechanisms of creativity nor developed alternative approaches to study the topic. This paper brings into sharp focus the three confounds — validity, false category formation, compound construct — that cripple this paradigm and shows how the use of in-vogue neuroscientific concepts — right brains, prefrontal cortex, default mode network, connectivity — might have contributed to the illusion of progress in the field. The paper concludes by putting forth five concrete steps towards a theoretical and conceptual restart: evolutionary algorithms, prediction system, dual-system view, Vaudeville conception, and valid subtypes of creativity.

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Current Opinion in Behavioral Sciences 2018, **27**:36–39

This review comes from a themed issue on **Creativity**

Edited by **Hikaru Takeuchi** and **Rex Jung**

https://doi.org/10.1016/j.cobeha.2018.09.001

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Creative thinking, and its derivative products — the knowledge and artifacts that make up human culture — is the fountainhead of human civilizations. Studying the brain mechanisms of creativity, therefore, is to approach the quintessence of our humanity. But there is also a practical dimension to this endeavor, as it would be an instant game-changer for any nation or company that gets an initial handle on how to improve the very invention machine that does all the inventing. From Google to every artist on the planet, from the world's medical associations to the U.S. military, everyone would be all over any research program promising to get us even the smallest of steps closer to that prospect. Given this, one would think that the neurocognitive mechanisms underlying creativity are the subject of intense research efforts in the behavioral and brain sciences, with dozens of labs and massive funding involved. But this is not the case. Only a few labs tackle this vexed problem empirically and funding is practically nonexistent. One has to asked why, given the paramount importance of the subject matter.

The main reason can be readily identified. The principle experimental method — a divergent thinking test in combination with neuroimaging — is fundamentally flawed [1,2•,3•], making the existing data fragmented and incomprehensible [4•]. And since there also is not an alternative approach at hand, the neuroscientific study of creativity has not grown to become the viable and lively area of research one would expect it to be. As a consequence, we know today next to nothing about the cognitive and neural mechanisms of creativity. Indeed, it is hard to think of a mental phenomenon so central to the human condition that we understand so little. This article examines how we got to this point and what can be done about it.

What are the problems?

There are three main problems, each lethal on its own, that render the current empirical approach to the neuroscience of creativity irreparably flawed. The findings from this paradigm, therefore, tell us nothing about how creative thinking happens in the brain.

First is validity. The psychometric measures of creativity have no demonstrated validity. This is not true for the larger Torrance Test of Creative Thinking (TTCT; [5]), which does possess some predictive value [6]. But neuroscience studies only use a small part of it, mostly the Alternative Uses Test (AUT; [7•]), which, unlike the full TTCT, first, solely rests on the concept of divergent thinking and second, reduces the multifaceted, hours-long TTCT to a minute-long test, for scanning purposes. Compounded by the sterile neuroimaging lab, a decisive factor given the mercurial and ephemeral nature of creative thoughts, there is no evidence that this assessment method has any real-world validity [1,2•,3•]. Not surprisingly, when presented with the short version of the AUT, people from outside the field typically have little trouble seeing that the emperor has no clothes. The lack of ecological validity also plagues the other main neuroimaging paradigm in which a musical melody is completed in either a set pattern from memory (control condition) or an improvization string ('creativity' condition) [8•]. But participants from such studies — professional musicians

most often — typically report that they do not consider what they did in the improvization condition to be creative. In sum, the purported neuroscientific 'studies of creativity' are not — studies of creativity.

Second is the false category formation. To continue with divergent thinking, everyone in the field acknowledges that one can also be creative with the exact opposite: convergent thinking. This raises the obvious question of what, exactly, is creative about divergent thinking? If both, divergent and convergent thinking, can lead to both, creative and non-creative thinking, the concept of divergent thinking is incapable of identifying the processes that underlie creative thinking! As such, the use of divergent thinking as a proxy for creative thinking makes no sense. The false category problem also applies to all other conceptions of creativity that have been tried over the years, such as defocused attention, remote associations, flow, madness, lateral thinking, low arousal, daydreaming, REM sleep, right brains, mindfulness, unconscious thinking, prefrontal cortex, or the default mode network [2•]. Given that their opposites also lead to creativity, they all fail to carve nature at the right joints.

Third is the compound construct. Like creativity, divergent thinking consists of many different, separate, and widely distributed mental processes with no one having the slightest clue what they are and in what mix [4•]. Although this problem is also widely acknowledged [3•,9,10], there is no effort underway to dissect divergent thinking and link it to the kinds of cognitive processes we use to operationalize all other psychological phenomena, such as working memory, cognitive control, semantic memory, perceptual processes, or executive attention. Incidentally, this compound construct problem also holds for the musical improvization paradigm. But it is only these clearly circumscribed and operationalized cognitive processes that neuroimaging technology can detect, not a complex psychological phenomenon that is defined by way of a false category formation. The compound construct problem has been partially overcome in other fields. For instance, neuroimaging studies on morality, surely a compound construct, use measures that zoom in on specific processes of morality, such as theory of mind or agency [11]. But this is not being done with divergent thinking. The psychometric test is always the same.

For neuroimaging, all three confounds — validity, false category formation, compound construct — combine to make defeat certain. Simply put, if you fail to isolate the subject matter of interest in your study, you cannot use neuroimaging to search for mechanisms. You just don't know what the brain image shows! To be clear, the problem is not the neuroimaging technology but our conception of what creativity is.

Aligning explanations with the current fashion

While the conceptual basis of creativity, and the way it is tested, has not changed at all since it was initially conceived by Guilford over 50 years ago, the explanations offered as possible brain mechanisms of creativity have become fancier and fancier over the years, broadly along the lines of what has been in-vogue in neuroscience at the time.

The first well-known proposal was the right-brain theory. It emerged in the 70s during the time of the first split-brain surgeries, most likely because the left hemisphere was found to be more involved in the analysis of information while the right was more associated with synthesis, a division that seemed to fit nicely with our romantic view of creativity [12]. The right brain has proven to be a particular vicious mutation of phrenology, probably because it was the first to metastasize to a global audience [13]. It was not until very recently that it was fully debunked by review articles of the field [10,14•].

With the arrival of neuroimaging tools in the form EEG [15,16•], the prefrontal cortex became the next candidate in this wild-goose chase to localize creativity in the brain, primarily due to its general position at the apex of human mental faculties. But with the use of functional MRI [17•], the explanation shifted again, this time to the default mode network (DMN) [18•]. Proposed by Raichle *et al.* [19], this network of brain areas shows heightened activity at 'rest' and is thought to support mindwandering, daydreaming, or moments of introspective thought. As was the case for the right-brain theory, this struck all the right chords with our overly simplistic and monolithic conception of creativity. The DNM was quickly linked to creativity, as it proved too irresistible for the myopic theorizing that has come to characterize this field. There is no reason, of course, that creativity could not also emerge from the central executive network (CEN), making the DMN association with creativity simply yet another false category formation [4•]. So, the latest proposal involves enhanced connectivity, or an interplay between the two networks [20], and the half-life of that idea is yet to be determined.

The all-important thing to remember here, and with all clarity, is this. All of the above claims, without exception, are extracted from one and the same incoherent experimental template: a divergent thinking test plus a neuroimaging tool. In other words, while the interpretations of the results have kept pace with current knowledge in neuroscience, the conception of creativity and the experimental method to test it has not. Yet it is clearly that side of the equation that needs change and development. With the three lethal confounds of validity, false category formation, and compound construct invalidating any findings from this paradigm, the neuroscientific study of

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