

# Neuroimaging as contributor to understanding creativity

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Data emerging from neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and neuroelectric techniques such as electroencephalography (EEG) contribute to, and often disprove, existing knowledge about creativity. This article explains why neural and cognitive aspects of brain states and brain processing will become germane to any future explanation of creativity.

**Key words:** creativity, neuroimaging, neural and cognitive processes

**Neurobeeldvorming as bydraer tot die vlugtige vooruitgang van insig in kreatiwiteit**

**Slutelwoorde:** kreatiwiteit, neurobeeldvorming, neurale en kognitiewe prosesse

Historically the formation of theories of creativity has been the preserve of psychology and philosophy (Boden 2008; Sternberg and Davidson 1995; Sternberg 1999, 2006; Sawyer 2012; Csikszentmihalyi 2002; Martindale 1993; Perkins 1981; Weisberg 1993, 2006). Natalia Bechtereva, Sebastian Danko and S.V. Medvedev (2007: 101) refer to the current psychophysiological literature containing more than 60 different definitions of creativity, referred to by them as the highest form of human mental activity. Such a wealth of definitions could fuel endless debates, yet “there is a certain consensus that creativity yields something partly or entirely new; gives existing objects new properties or characteristics; allows one to imagine new potentialities not conceived of before and to see or perform something in a manner different from what was thought possible or normal previously”.

The wealth of definitions pertaining to creativity and the consensus referred to above have commensurately resulted in efforts to measure and explain it. Initial research on creativity based purely on psychological findings was followed by ground breaking research into the neural and cognitive underpinnings thereof. It was the advent of neuroimaging technology that contributed to a more complete understanding of this seemingly elusive phenomenon. This article elucidates.

## Measuring creativity

Psychology is the discipline that pioneered the research and initiated descriptions of creativity. Between 1950 and 1970 personality psychology, in terms of creativity, attempted to explain the creative personality and this era included an important first wave of creativity research. This was primarily formulated by, amongst others, Ellis Paul Torrance, Lewis Terman, Jacob Getzels, Douglas Jackson, Donald MacKinnon, Frank Barron and Donald Treffinger. However, personality psychologists had yet to establish what personality traits distinguish creative people from ordinary people and had yet to develop a test that could identify exceptional talent early in life (Van Heerden 2010: 142).

Several psychological or psychodiagnostic test batteries that indicate propensity for creativity have been developed and are widely utilised – these include Joy Paul Guilford’s (1967) Unusual Uses Divergent Thinking Test; the Biographical Inventory of Creative Behaviours; the Self-Rating of Creativity (SR) test, and the Barron-Welsh Art Scale (Furnham and Bachtiar, 2008); Torrance Tests of Creative Thinking (Wechsler 2003; Almeida et al. 2008); Wechsler family of intelligence tests (Banich 2004: 104-106); Rorschach Inkblot Test (Zillmer and Spiers 2001:461-463); Mednick’s Remote Associates Test (Fink and Neubauer, 2006); and Cattell’s Sixteen Personality Factor Model (Boshoff-Prinsen 2011).

Psychologists Robert Sternberg and Linda O’Hara (1999: 254) describe research that explored the possible link between creativity and intelligence – these included Guilford’s 1950s, 1960s and 1970s models, Torrance’s model (from the 1970s), as well as Raymond Cattell’s (1970s) list of primary abilities. These are: 1) linguistic, 2) logical mathematical, 3) spatial, 4) bodily-kinaesthetic, 5) musical, 6) interpersonal, 7) intrapersonal, and 8) naturalist abilities. This was followed by Howard Gardner’s theory of multiple intelligences (MI), noteworthy for suggesting that creative functioning is one aspect (a subset) of the multiple intelligences. Sternberg and O’Hara (1999: 255-7) explain other views (which includes Benjamin Bloom’s Taxonomy of Educational Objectives) that intelligence, on the other hand, can be viewed as a subset of creativity, that creativity and intelligence are overlapping sets, that creativity and intelligence are coinciding sets, and that creativity and intelligence are disjoint sets. More recent research exploring this relationship was conducted by, amongst others, Charlton (2009); Furnham and Bachtiar, (2008); Furnham et al. (2007); Preckel, Holling and Wiese (2006); and Silvia (2008). Fink and Neubauer (2006:48) refer to psychometric tests for intellectual abilities that provide scores for specific intellectual abilities such as verbal, numerical and visuo-spatial, in addition to tests for total intelligence quotient. These are sometimes combined with tests for personality traits (referred to as the “big five model” – i.e. extraversion, agreeableness, conscientiousness, neuroticism, openness and experience).

Mihaly Csikszentmihalyi (2002) refers to two types of intelligence regarding creativity: fluid intelligence, which is regarded to be innate (and thus marginally affected by learning) – the ability to respond rapidly, to have quick reaction times; and secondly crystallised intelligence, which is more dependent on learning than on innate skills – abilities that depend more on reflection than quick reaction, and which seem to increase with time. Seemingly, creative people depend more on crystallized intelligence. In addition to conventional tests, unorthodox approaches to intelligence and creativity are emerging – Bruce Charlton (2009:237) associates high creativity with moderately high levels of Hans Eysenck’s personality trait of psychoticism. “Psychoticism combines qualities such as selfishness, independence from group norms, impulsivity and sensation-seeking; with a style of cognition that involves fluent, associative and rapid production of many ideas” (Charlton 2009: 237).

According to creativity researchers Adrian Furnham and Velicia Bachtiar (2008) creativity researchers suggest that multiple components indicate creativity in the individual – these include cognitive ability, personality factors, cognitive style and motivation. However, neuroscientist Arne Dietrich (2007b) cautions that since there is scant sound empirical data on the mechanisms underlying creativity, current psychometric measures of creativity possess little validity and/or predictive power.

Such paucity was noted and over time, with regard to an understanding of creativity, personality psychology was gradually replaced by cognitive psychology, the focus of which

analyses creative mental processes and examines the representational structures of the brain, their interconnections and the mental processes that transform them. Cognitive psychologist Antonio Damasio (2007:3) refers to the key instrumental resources of cognition as perception, movement, memory, language, and reasoning – cognitive psychology thus considers all such resources when identifying creativity. With regard to cognitive psychology, seminal work was done by Jerome Bruner, John Guthrie, George Miller, Ulric Neisser, Jean Piaget, and Edward Tolman.

During the 1950s Donald Hebb, and the 1960s Karl Pribram contributed seminal work with regard to technological advances in measuring creativity by observing the body. Anthropologist Richard Klein, argues that the discovery of the FOXP2 gene demonstrates that creativity may have evolved 200,000 years ago (Klein 2008). Wade (2003) refers to FOXP2 and significant developments in language that took place around 100,000 years ago. Despite genetics, biology, however, is engaged to help explain creativity as a result of studies in neuroscience, mental illness and evolutionary theories.

Neuroscientists Charles Limb and Allen Braun (2008: 2) refer to creativity as a quintessential feature of human behaviour, yet the neural substrates that give rise to it remain largely unidentified: “Spontaneous artistic creativity is often considered one of the most mysterious forms of creative behavior, frequently described as occurring in an altered state of mind beyond conscious awareness or control[...] while its neurophysiological basis remains obscure.” Neuroimaging techniques or methods have rendered such a supposition outdated; as Limb and Braun (2008: 2) confirm – creativity is “predicated on novel combinations of ordinary mental processes” which are not associated with so-called altered states of consciousness. Thus, whereas this article will not discuss the neurophysiological processes involved in altered states of consciousness, it becomes important to investigate the origins of novel combinations of ordinary mental processes in order to understand creativity. The neural and cognitive underpinnings of creativity point the way.

### **Neural and cognitive underpinnings of creativity revealed due to neuroimaging findings**

In order to understand the neural and cognitive processes underlying creativity, there are essentially three phenomena that could offer clues: brain anatomy; cognitive processes; and neural processes. Information is thus required as to the anatomical structure related to mental functions; how complex properties of the brain are instrumental in allowing behaviour to occur; and lastly, how information is processed in the brain. It is not assumed that brain processes that underlie creativity – cognitive or neural – can necessarily be dissociated anatomically or otherwise. Yet, an investigation of their key components are prerequisites.

The greatest contributions to research on creativity have emerged from the disciplines of cognitive psychology, neuropsychology and cognitive neuroscience, utilising some of the current neuroimaging techniques available such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET). Other techniques that have been used in creativity research are: single photon emitted computed tomography (SPECT) and near-infrared spectroscopy (NIRS). Neuroelectric techniques have also been used in research on creativity, of which electroencephalography (EEG) has been used in laboratory experiments.

The sheer variety of studies conducted, the particular focus of a study, the different data capturing methods utilised, as well as the interpretation of empirical results, all contribute to increased understanding of creativity. Lesion and neurodegenerative illness studies have expanded understanding of the cognitive basis of visual processing, as well as the visual systems used by artists in the process of art making. The localisation of specific brain regions vis-à-vis creativity is limited by the variations in human anatomy, and the infinite formal choices that artists and designers make. Menek Goldstein (2008: 43) defines localisation of function as “[t]he idea that different brain areas serve different functions.” For example, the temporal lobe is found to be important for language, memory, hearing, and perceiving forms, whereas the frontal lobe serves higher functions such as language, thought, memory, and motor functioning. Sawyer (2012) suggests that the domain (such as fine art or physics) determines the location of activity and creativity in the brain, as do different subcomponents of ability in a single domain – this can be explained by the different motor areas that are engaged with specific tasks or actions. In addition, the location of these subcomponents appears to differ in trained and untrained individuals (of any specific discipline).

Narayanan Srinivasan (2007) refers to problem solving tasks or open-ended tasks that are used in creativity research that show that the prefrontal cortex is activated during effortful problem solving tasks. Bekhtereva et al. (2001: 390) report on EEG studies where an increase as well as a decrease in the activity of the frontal lobes of the cortex was evident during creativity tests. This may be a result of a specific stage of problem solving that has already been achieved, or might indicate that the subject was in the brain state referred to as flow – during flow cerebral cortex activity tends to shift from frontal to parietal regions of the cortex. Ingegerd Carlsson, Peter Wendt and Jarl Risberg (2000) investigated the relationship between creativity and hemispheric asymmetry, as measured by regional cerebral blood flow (rCBF). The hemispheric differences were very pronounced in so-called low creative subjects (rated on Smith and Carlsson’s Creative Function Test (CFT), which was developed especially to study the creative person’s visual perception). Highly creative subjects showed a bi-lateral response. Based on theoretical as well as experimental work, Carlsson, Wendt and Risberg (2000: 874) “...assume creativity in the neuropsychological frame of reference to be a functional system, comprising the interaction of the cognitive functions in the hemispheres, as well as the directive and executive functions of the frontal lobes”. Dietrich (2004a) found that creativity is enabled by the cognitive capabilities provided primarily by the dorsolateral prefrontal cortex (DLPFC), which is involved in executive function. The complexity of attempting to “pin point” a particular location for creativity thus becomes evident.

“As early as 1948, Alajouanine recognized the hemispheric specialization for linguistic, musical, and visual arts” (Liu and Miller 2008: 472). Since the neurologist Théophile Alajouanine’s studies, a progression of lesion studies has demonstrated that the two cerebral hemispheres are indeed specialised, but that handedness affects the distribution of function between hemispheres (Liu and Miller 2008: 473). Neuroscientist Gussie Klorer (2005: 214) explains that developmental changes in the human infant follow the emergence of functions localised initially on the right cerebral hemisphere, representing the visuospatial, control of sensorimotor perception and integration, and also the processing of social-emotional input. Thereafter language abilities become localised on the left cerebral hemisphere. Klorer (2005: 216) further suggests “that traumatic memories may be stored in the right cerebral hemisphere, which would make verbal declarative memory of the trauma more difficult [compared with other means of expressing traumatic memories].” In verbal therapy, there is thus often a neurobiological explanation why verbalisation is not always a successful method, whereas art

therapy, affording access to feelings in the emotional centres of the right brain, may well succeed. In the adult human, the left cerebral hemisphere accommodates symbolic meaning experienced in artwork, has links with literal meaning or subject matter, and tends to focus on detail. The right hemisphere is geared for overall form and composition and is functional vis-à-vis response to, and the generation of, the manner or style of the artwork.

According to Liu and Miller (2008: 472) a basic assumption of neuroscience is that learning a skill, and by implication becoming proficient therein, will lead to specific neuroanatomical and neurophysiological brain changes. Ramachandran and Hubbard (2003: 68) note that during recent human evolution, frontal areas have increased disproportionately in complexity and size, and moreover, may explain the creation of art by humans, but not other species. One could be drawn to conclude that creativity must reside in the frontal cortex. However, Dietrich (2004b: 1011) cautions that “no suggestion is made here that the prefrontal cortex is the “seat of creativity”. Rather, the prefrontal cortex contributes highly integrative computations to the conscious experience, which enables novel combinations of information to be recognized as such and then appropriately applied to works of art and science”.

Thomas Ward (2007: 29) states that creativity is a complex and multifaceted phenomenon, requiring a variety of methods to investigate it, from a multitude of perspectives. Dietrich (2007a: 24) seems to concur with Ward when he states that the “problem” with creativity research is that creativity is treated as a monolithic entity – for example, that it can seem to be defined as residing in a specific brain area, or to conform to a specific thinking process. In terms of pin-pointing creativity, Ward (2007: 29) suggests that since creative activities clearly rely on accessing stored knowledge, some ways of accessing knowledge may be more conducive than others to the development of original ideas, thus contributing to the ongoing development of further original and practical ideas. Psychometric measures of creativity draw on a combination of mental processes, yet results are often discussed in terms of “the whole” of creativity. This is inaccurate in an attempt to describe the localisation of function (thus how it maps onto brain areas vis-à-vis creativity) as meaningful. However, the individual mental processes that combine to make a creative idea can possibly be localised. When “mapping” brain function with brain structure Vilayanur Ramachandran and Sandra Blakeslee (1998), and Ramachandran (2005) postulate that creativity is the result of integrated brain function and location. Jung et al. (2010: 400) concur and expand on this notion when they state “that a construct as complex as creativity will never be “localized” in the brain – be it the right hemisphere, anterior cingulate cortex, or other locus. Rather, individual findings will be dependent upon the task used as a “proxy” measure (e.g., insight, DT [divergent thinking], convergent thinking), the population under scrutiny (e.g., college undergraduates, experts), and even methodological issues related to structural versus functional brain characteristics”.

### ***Outdated notions of creativity***

Creativity is often assumed to reside in the right brain, an outflow of the field of cerebral hemispheric specialisation. Dietrich (2007a: 23) disagrees: “the left-brain/right-brain craze that has taken hold of popular culture underscores the need, in clear and vivid form, of how important it is to systematically demolish ideas gone bad [...]. Such was the case for the right brain meme”. Dietrich (2007a; 2007b) suggests that outdated information about creativity should not be used as the basis for observation and empirical research experiments and cautions researchers against describing the pioneering work of Guilford or Sarnoff Mednick from the

1960s as part of the rationale for setting up experiments – they should rather refer to such pioneers for historical background. These pioneers proposed that creativity can be captured with the concept of divergent thinking; involves the exploration of remote associations (RAT) (Mednick 1962; Houston and Mednick 1963; Mendelsohn 1976); and is located in the right hemisphere (Martindale et al. 1984). Unlike cognitive psychology, joined by neuroscience some time later, which together unearthed the functioning of higher mental processes and devised new theories and methods at an ever accelerating rate, Dietrich (2007a: 22) is of the opinion that the experimental study of creativity has largely remained stuck in outdated ideas and methods – “[it] held on like grim death to the few ideas and methods it developed in the early days of cognitive psychology”.

An example of an outdated concept of creativity is divergent thinking. Sawyer (2012) suggests that to conduct experiments for creativity based on divergent thinking (associated with problem finding) alone, would offer an incomplete picture on creativity, as creativity is also associated with problem solving (convergent thinking). According to Dietrich (2007a: 24) creative ability involves both cerebral hemispheres. Carlsson, Wendt and Risberg (2000: 882) explain that the right frontal lobe is more involved in spontaneous production of non-verbal representations – the left lobe “may exert control and secondary evaluative and verbal analysis”. Thus it seems that there is cooperation and coordination between the two lobes, and that creative performance is reflected in those who can access and are efficient in using the cognitive mode supported by the complementary cerebral hemisphere – “an overemphasis on convergent thinking [associated with the left cerebral hemisphere] may hamper the development of divergent thinking [right cerebral hemisphere association][...], or indeed, the reverse” (Carlsson, Wendt and Risberg, 2000: 883). With regard to brain architecture, Richard Restak (1993: 170) refers to creativity requiring a constant dialogue between the cerebral hemispheres – “the imagery and symbols generated by the right hemisphere require the left hemisphere to translate them into creative verbalizations”.

As far back as 1990 Klaus Hoppe and Katherine Neville found that creative subjects tend to have freer access to mutual interaction in both cerebral hemispheres and thus that creative people have enriched communication between their hemispheres. Recent split-brain research infers that the difference in the way the two cerebral hemispheres function might provide clues about the nature of human consciousness. In this regard cognitive neuroscientist Michael Gazzaniga (2008: 39) states that “In an intact brain, the two systems complement each other, allowing elaborate processing without sacrificing veracity...”. Thus, one could conclude that creativity is a function of both cerebral hemispheres, involving frontal, central, temporal and parietal areas of the brain, in varying degrees, depending on the tasks at hand. However, the brain is most likely to integrate creative activity in the frontal areas thereof.

Divergent thinking, or out-of-the-box thinking, entails cooperation among many different cerebral areas and involves both hemispheres. Ward (2007: 29) refers to criticism levelled at traditional psychometric approaches (such as relying heavily on fluency and flexibility scores from divergent thinking tests as indicators of creative functioning). From a cognitive perspective divergent thinking tests do not “provide a precise characterization of the processes that underlie creative accomplishment”. The same author explains that a wide range of processes may be applied, such as episodic retrieval, mental imagery, analysis of features, or abstraction. In this regard the divergent thinking score is merely the end result, whereas the underlying processes are doing the (creative) work, requiring a detailed consideration of the processes that were involved in building up the score to characterise the creativity in question. Ward (2007: 36)

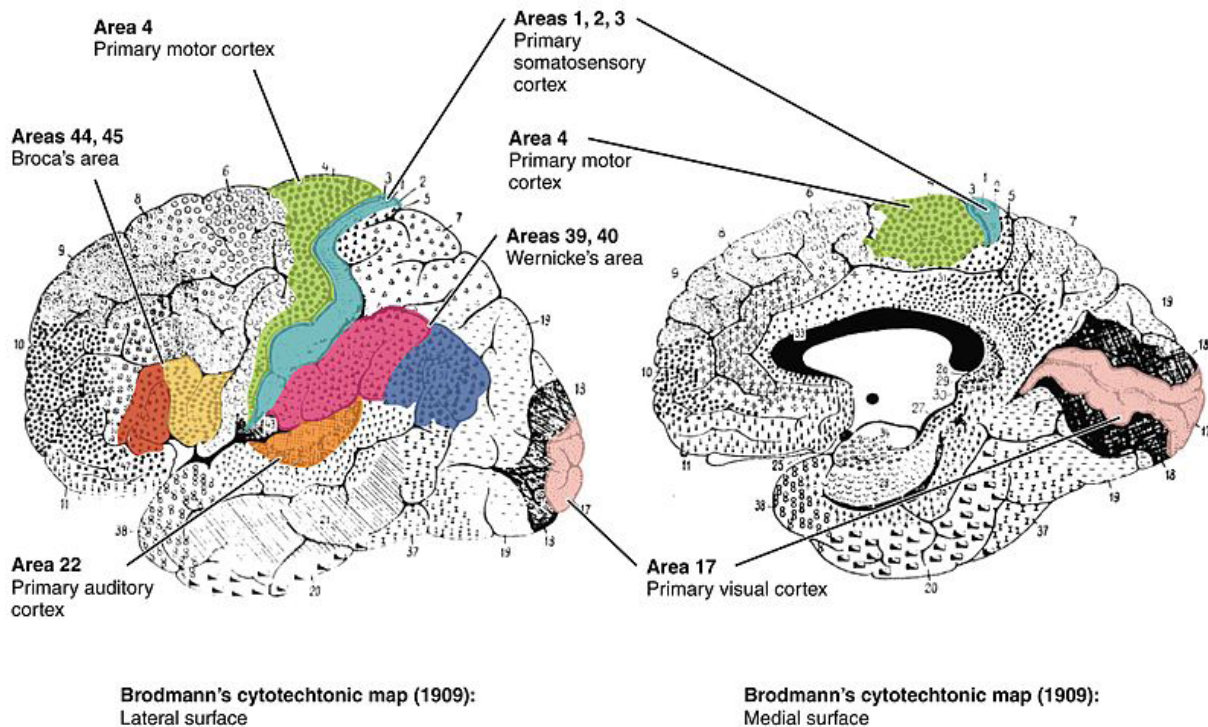
further cautions against sole reliance on global cognitive descriptors (such as divergent thinking), and rather promotes the creative cognition approach that “seeks to specify the basic component process that lead [sic] to divergent productions, such as retrieval, combination, analogy, and so on.” This leads to better understanding of the nature of basic cognitive processes, as well as “how they operate on knowledge structures to produce original and task-appropriate ideas”. In this sense, creativity is accepted to emerge, rather than to “arrive in a flash”. This position is consistent with the finding that even though integrative creativity activity occurs in the frontal areas of the brain, the components of creativity may occur in different regions of the brain. Two neuroscientific researchers, in particular, set out to investigate this notion.

### ***Dietrich and Kanso’s review of neuroimaging and neuroelectric studies on creativity and insight***

Dietrich and Kanso (2010) reviewed neuroimaging and neuroelectric studies designed to investigate creativity and insight. From an initial 1910 articles published in English, 73 experiments reported in 63 articles published until February 2010 were reviewed, of which seven were reports on experiments which included visualising, looking, imagining and drawing. Their findings revealed that “both EEG and neuroimaging experiments fail to support the notion that divergent thinking, and by extension creativity, is linked to the right brain – or to the left brain for that matter [...]. Divergent thinking, at any stage, entails cooperation among many different cerebral areas and involved both hemispheres” (Dietrich and Kanso 2010: 833). With the exception of the prefrontal cortices, there is also no special role of any anatomical locus in divergent thinking.

Dietrich and Kanso’s review of brain imaging and artistic creativity referred to above underscore findings that even though integrative creativity activity occurs in the frontal areas of the brain, the components of creativity may occur in different parts of the brain. In their review seven studies used EEG (related to insight studies), five fMRI and one used positron emission tomography (PET). In total seven studies were on art, of which only five involved making drawings, none of which were in “real time”. A summary of that review reveals that:

- Creativity requires multiregional, interhemispheric interactions.
- Creativity is not a function of the right hemisphere.
- Activation was found in the temporoparietal areas, fusiform gyrus, several visual cortices, thalamus, basal ganglia, hippocampus, cerebellum, midbrain and pons.
- There were deactivations over a wide limbic and paralimbic area, such as the hippocampus, amygdala, entorhinal cortex, hypothalamus, parahippocampal gyrus, also parts of the parietal and occipital cortex.
- Equal amount of evidence indicates that creativity can also be linked to deactivations, thus hypofrontality – this indicates the downregulation of any metacognitive, supervising processes, which result in more intuitive action.



**Figure 1**  
**Brodmann's areas (BA) of the human cerebral cortex.**  
 (retrieved from the public domain [https://upload.wikimedia.org/wikipedia/commons/thumb/4/44/1307\\_Brodmann\\_Areas.jpg/480p](https://upload.wikimedia.org/wikipedia/commons/thumb/4/44/1307_Brodmann_Areas.jpg/480p)).

- Five studies reported activation in various areas of the prefrontal cortex, including premotor and supplementary motor areas (both parts of BA 6) motor cortex (BA 4), frontal gyrus (BA 8 and 9), frontal operculum (BA 44/45), dorsolateral prefrontal cortex (DLPFC), representing (BA 46) and the anterior cingulate cortex (ACC) – see figure 1.

To further explain how creative thought comes about, Dietrich (2004a; 2004b) suggests that creativity results from the factorial combination of four distinct kinds of mechanisms, each mediated by a distinct neural circuit. Neural computation that generates novelty can occur during two modes of thought (deliberate and spontaneous) and for two types of information (cognitive and emotional). Not only can these two functional systems be dissociated by the way they process information, but also anatomically. Dietrich (2004b: 1018) explains that creative insights are not exclusively of one particular type – rather, that these four types should be understood as the extremes of two dimensions, which are deliberate/spontaneous and cognitive/emotional. Creative works arise from a mix of these four basic components. Dietrich (2004b:1023) continues: “Regardless of how novelty is generated initially, circuits in the prefrontal cortex perform the computation that transforms the novelty into creative behavior. To that end, prefrontal circuits are involved in making novelty fully conscious, evaluating its appropriateness, and ultimately implementing its creative expression”.

Based on the assumption that creativity is both novel and appropriate, the cognitive flexibility germane to the prefrontal cortex is instrumental in assessing whether a particular new behaviour is creative, as opposed to merely new. Dietrich (2004a: 759) hypothesises that the implicit system can only contribute to generating novelty, which is not always necessarily

creative. This suggests that creativity may require more explicit grounding, whereas novelty may be reliant on implicit cues. This furthermore has implications when observing deactivations in areas of the brain and assessing the role of intuition in so-called creative acts (which may actually be novel rather than creative).

## Conclusion

From a neuroscientific perspective neuroimaging has revealed that creativity is a function of both cerebral hemispheres, depending on the task involved and the action required. It is most likely to involve activity in the frontal, central, temporal and parietal areas of the brain, in varying degrees, depending on the tasks at hand. Thus, “subcomponents” of creativity may occur in different parts of the brain, with the final integration thereof occurring in the frontal areas of the brain. Notions of exclusively right-brain activity associated with creativity are thus outdated. Notions of exclusively divergent thinking (so-called out-of-the-box) are out-dated. Handedness and notions of dominant hemisphere creativity are not definitive in art making and creativity may involve divergent and convergent thinking. With regard to the cognitive and neural processes involved in creativity, one could say that neuroimaging technology has contributed to the most rapid understanding of creativity to date. Neuroimaging, as well as neural and cognitive aspects of brain states and brain processing are now germane to any future explanations of creativity and the visual arts.

## Notes

1. Personal consultation on psychometric testing methods used in the private practice of Dr. Louise Boshoff-Prinsen at Pretoria, 16 February, 2011.
2. Subjects/participants experienced a test battery: Creative Function Test (CFT); rCBF; anxiety inventories; intelligence tests; personality tests; blood samples for hormone analysis; and an interview. Thus, findings were based on multi-modal data.
3. BA refers to Brodmann’s areas of the cerebral cortex. Anatomist Korbinian Brodmann split the brain into areas and assigned numbers.

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