Brain and Creativity

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Creativity can be considered from different points of view. A first possibility is to trace its natural history in mammals, mostly in non human primates. A second one is to consider mental processes, such as analogies, that may result in creative associations as evident in many fields, from arts to sciences. These two approaches lead to a better understanding of cognitive systems at the roots of creative behaviour. A third strategy relies on an analysis of primary and secondary states of mind characterizing flow and creativity. Flow, the mental state of operation in which a person is fully immersed in what he or she is doing, typical of intense problem solving activities, has been explained in terms of reduced prefrontal activity. While it is not difficult to carry out tests of problem solving activity, creativity is much more elusive and it is not easy to measure it. Thus, flow has often been simplistically assimilated to creativity and it has been assumed that also creative performance depends on low prefrontal activity. It is instead proposed that creativity involves two consecutive steps: 1. Generation of novelty, mostly in the ventral striatum. 2. Analysis of novelty by the prefrontal cortex that transforms it into creative behaviour. The emergence of creativity has been explained through a Darwinian process based upon the classic variation-selection procedure. Thus, basal ganglia, with their implicit strategies and memories, may be regarded as a mechanism that continuously generates novelty (variation) while the prefrontal cortex, possibly its dorsolateral areas, may be considered as the computational mechanism that transforms novelty (selection) into explicit creative behaviours.

§1. What is creativity?

Definitions of creativity are often unsatisfactory but in the most general terms they relay to attitudes, capacities and behaviours leading to some innovatory outcome. Creativity reflects an enhanced intensity of perception, cognition, and expression which occurs either spontaneously or is elicited by specific stimuli to relate and integrate variables not ordinarily associated with each other.[1] Thus, when we refer to creative behaviours we also consider it in terms of a number of capacities which change and ripen during development and are characterized by a long natural history. As a matter of fact, creativity applies to a child that makes an innovatory use of a toy or of some amorphous material in order to adapt them to an alternative function, but also to an animal that solves a problem outside its usual stereotyped repertoire.

If we look at creativity from a broader point of view we can relate it to a number of functions and characteristics of our brain, namely its plasticity and ability to elaborate a plurality of mental schemes and visions of the world. Each mental function comprehends a number of plastic, creative facets: these are evident within perception, memory, mental imagery and representations of reality, during diurnal activities as well as dreaming. The origin of creativity depends on the gap existing between the real world and its mental representations: in fact, there are not facts or experiences that are represented straightforwardly, as to say without being interpreted and screened through hypotheses corresponding to a theory, a vision of reality. If our brain just limited itself to register of information, to the formation of "neutral" memories through a computer-like process of categorization without diverging from strict rationality and from logic-computational strategies, there would be no room for plastic, divergent, creative mental processes. For example, the continuous reconstruction of memories, their re-consolidation,[2)–4)] their contamination caused by experiences occurring in succession, their conscious or unconscious reorganization belong to plastic, creative processes leading to a representation of reality that deviates from its initial core.

If we consider creativity in terms of its neural bases, a first classical approach refers to the different functions of the two cerebral hemispheres. From the one side we are endowed by logic-symbolic activities that mostly depend on language and therefore on the left side of our brain. From the other side, "holistic" activities lead to a strategy that also considers the ensemble of a number of facts, in particular emotional facts, and depends on the right hemisphere. Even if the characteristics of hemispheric functions are more variegated and less clear-cut, we cannot minimize the fact that the left half of our brain exerts a preponderant role in symbolic-linguistic activities, as to say in computational processes, a fact that is at the ground of those theories of mind that assimilate biological and artificial intelligence.

Many studies, mostly based on assessment through functional magnetic resonance, are centred on the asymmetric role of the two cerebral hemispheres. These studies suggest that creative solutions are associated to the fact that the left hemisphere is "switched off" while the right half of the brain is turned on: this state gives way to fluid associations, metaphors, analogies at the ground of new points of view, as to say of creativity.[5),6)]

The role of the right hemisphere in the discovery of a solution or of new explanations is emphasized by the fact that this hemisphere is involved in a number of functions such as musical perception and production, visual imagery and visual artistic creations, as indicated by Michael Gazzaniga.[7)] The same hemisphere is also implicated in the production of associations when verbal stimuli are used. It is well known that, due to the architecture of visual pathways, a visual stimulus (such as a written word) sent to the left visual field is processed by the right hemisphere while a visual stimulus sent to the right visual field is processed by the left hemisphere. Verbal stimuli processed by the right hemisphere result in a higher number of mental associations, and more specifically in richer associations and analogies, than stimuli processed by the left brain. By using functional magnetic resonance it has also been possible to indicate that the sudden discovery of the solution of a problem is a process that mostly involves the right hemisphere:[8),9)] more specifically, when the subjects discover the right answer in a test, the temporal lobe of their right hemisphere undergoes a quick activation. The activation of the right antero-superior temporal gyrus is preceded by a quick change of activity at the level of the prefrontal cortex, an area involved in a number of cognitive, executive and attentive tasks. This separation of hemispheric competencies often results in a notion of creativity in which right-brain functions are assimilated to creative, emotional, "instinctual" processes in antagonism to left-brain rationality and semantic, cognitive activities.[10)]

§2. A natural history of creativity

From an evolutionary point of view, creativity involves both the process and product of unprecedented or novel perception, thoughts, or actions by which an animal or a species copes with present or potential changes in the structure of its environment. In order to trace a possible natural history of creativity, as to say the evolutionary development of the creative potential of the brain and of its innovatory aptitude, we can start from the broad behavioural diversification evident among different animal species. There are species characterized by higher levels of behavioural rigidity, as to say by a trend towards stereotyped, scarcely variable responses which depend on instinctive mechanisms, and more plastic species in which an individual behavioural repertoire may be evident in response to environmental constraints or novelties.[11)] What are the advantages of these two conditions? In a homogeneous, slowly changing environment behavioural specialization is an advantage, though there is the risk that sudden changes do not result in adaptive mechanisms, a fact that may put at risk the survival of a species. From the other side, a non-specialized animal who relies on a broad number of behaviours organized through its individual experience, spends its entire life to solve those problems that are solved by the genetic patrimony of a specialized animal. While specialized species depend on instinctive patters determined by genetic memories, generalist species are more flexible, acquire new behavioural patterns through individual experience and are also able to temporarily assemble different behavioural patterns to solve new problems.

But what makes a species plastic and able to find new and creative solutions? The difference between specialized and non-specialized species does not depend on the level of cerebral complexity only. There are in fact other mechanisms resulting in behavioural variability such as varied diet, safety from predators and also living in a "relaxed" social context, a non agonistic environment allowing a "hedonistic attitude":[12)] freedom from predators and enemies favours strategies more plastic than those semi-automatic patterns set by instincts. Behavioural variability also depends on two important factors: dreaming and playing. As indicated by a large body of experiments, the REM (Rapid Eye Movements) sleep phase in which most of dreams occur has an important role in terms of shaping neural circuits. In human infancy dreaming activity is at its peak and during REM periods neural circuits are shaped through synaptic pruning and consolidation of those synapses involved in critical experiences.[13)] It is during the REM phase that memories are categorized and consolidated and that non relevant information is downloaded from neural networks.[14)] In addition to that, dreams are characterized by a sort of mental kaleidoscopic activity leading to a rich imagery and unconscious mental dynamics that do not generally take place during waking.

Play is a behavioural activity evident in higher mammals but almost absent in other species. During play brain activity is at its peak:[15)] in children, open air games involve a number of sensations, perceptions, emotions, movements and, most of all, a strong cognitive activity. One of the functions of play is to stimulate brain development and cognition: this explains why its role increases during infancy in light of a positive correlation between play and brain and cognitive growth.[16)–20)] In fact, the developmental curves of play and brain growth overlap in all mammal species and reach their peak at pre-adolescence, a developmental phase characterized by increased synaptic connections, dendritic growth and myelinisation of a large number of nervous fibres resulting in increased functional brain capacity. Among other data, augmented c-FOS protein synthesis during play indicates that this activity has a positive neuronal trophic effect.[21)]

Obviously, a varied diet, safety from predators, a "hedonistic" environment, REM sleep and play are prerequisites but not synonymous of creativity. However, a variable and plastic behavioural repertoire may be considered as a precondition of creative behaviour. Different studies, mostly on primates, analyze factors leading to variable responses. One of the behavioural activities taken into consideration is the manipulation of non-edible objects. Glickman and Sroges,[22)] conducted a seminal study on more than 100 animal species, ranging from reptiles to non-human primates, in which they assessed reactivity –or curiosity– as measured by visual orientation towards a new object and its manipulation (number and type of body contacts with the object). Within primates, clear differences are evident in terms of both curiosity and object manipulation: gorillas, orang-utans or chimpanzees were the most exploratory, gibbons and macaques occupied an intermediate position while new world monkeys were characterized by a scarce body interaction with new objects. In general, anthropomorphic primates make contact with the object through a large number of body parts. They also make a large number of non-stereotyped movements in which the object is involved and make use of the object as a tool. Anthropomorphic primates also tend to innovate, are less repetitive, get easily tired of a movement already practiced or of a use of an object already known: despite that, they do not completely lose their interest in the object –for example a rope or a stick– and give birth to new behavioural patterns in a kind of recombination play. It is from this play that a novelty may suddenly emerge, thus being co-opted in the behavioural repertoire of the animal.[23)] In conclusion, the most meaningful behavioural innovation stemming from the large development of the associative cortex of anthropomorphic primates is the variety of actions and uses that an animal makes with an object. This eventually leads to sophisticated hunting strategies, cooperative behaviours and cultural transmission.

To sum up, anthropomorphic monkeys probe different possibilities and interactions with reality, through a mixture of exploration, curiosity and "analytic" attitudes deployed in a direct, concrete way. This attitude is not very different from that of a child playing with wood blocks, building different towers, exploring different combinations: the results of his play are often unpredictable and hardly separable from the hypotheses about the consequences of his own actions.

§3. The creative potential of analogies

A central aspect of creativity is the ability to combine and mix in a new way an already existing "capital", as to say to use the resources available as "bricks" to build new associations. As indicated by the mathematician Henry Poincaré,[24)] "To create means to make new combinations of useful associative items. Creative ideas show relations between facts that are already known but that are erroneously believed to be unrelated to each other".

An important aspect of creativity is therefore the ability to pick up analogies between mental items that until a given moment do not seem to be associated. New ideas do not generally stem from deductive reasoning: on the contrary, very often ideas emerge from mental images. The use of analogies allows to grab similarities and relationships among objects, experiences and facts in order to fill a cognitive gap or to solve a problem through prior experience and knowledge. Analogies embody abstract concepts by building a mental model of a reality that otherwise cannot be easily represented since it is far from our senses. This strategy allows many informal artists to give body to concepts that would be otherwise difficult to translate. This embodiment of ideas that our senses do not seize, implies that our mind does not mirror a real world but artificially builds a new one.

Analogical thinking[25)] draws therefore from previous experiences and memories and generates new meanings. This approach, as indicated by Amabile,[26)] increases the possibility to lead to creative results. An approach only based upon logics and on its strict rules does not in fact leave much room to those playful associations that are possible when we abandon ourselves to imagination and reduce logic control. There are two cortical regions that are involved in the production of analogies, associative and prefrontal cortex, the latter being much expanded in humans in relation to other mammals and primates. As indicated by its name, associative cortex makes possible an association between different components of the same experience. For example, to know somebody means to memorize her face, voice, the context in which we met her, the emotional reactions involved such as sympathy, indifference, antipathy and so on. These different components of experience are distributed throughout a range of cortical territories and later re-associated thanks to the role of the associative cortex: this procedure generates again the fullness of a given memory. By starting from a single cue, for example the tone of the voice, the associative cortex restores the critical aspects of a face, the emotions involved and so on. The prefrontal cortex, may instead be considered as a sort of dynamic filter, a depository of representations where it is possible to select those items that are most critical in order to give an answer to a specific request. For example, if I ask somebody to tell me the colour of the air of his friend he will be able to answer also because other disturbing information, such as those related to the tone of his voice or to the environment in which we meet him, are blocked. If a person gets confused, he might react to the same question by answering that his friend has a very sharp tone of voice or that he is very agreeable.

When analogies are created, the prefrontal cortex selects the information while the associative cortex interconnects common items, by comparing for example blonde hair to a golden sunset, to gold etc. What is the structure of analogical thinking? In their simplest form analogies imply the transition from a source –or known matter– to a target or unknown matter. For example, when we face a new situation, such as a working problem or a new relationship with an unknown person, we make an automatic use of analogy, as to say our mind automatically searches for a previous situation which may be assimilated to the new one and proposes a solution in line with the previous way out. In a similar way, a scientist facing a new reality will try to solve it by applying to the new context an analogy based on previous knowledge. Different types of logics play a role in the elaboration of an analogy. For example children will build up analogies on the ground of “magic” thoughts, typical of infancy, while adults or scientists will produce analogies that must be screened through logics in order to judge if they are plausible and useful.

Analogical thinking is not grounded on usual logic deductions: however it implies a form of logics (ana-logics) that leads to an understanding of an unknown reality though a series of constraints. It is necessary to proceed through these bottlenecks in order to configure an analogy useful to elaborate a map of the unknown target on the ground of known information. Thus analogies represent an experimental tool in order to afford new situations or to formulate new theories. James Maxwell, for example, made use of his knowledge of the properties of water waves in order to hypothesize the behaviour of sound waves when they hit a solid surface (such as it happens to sea waves when they hit a rock) or when they hit each other.

Obviously, grabbing new relationships may happen by chance if we just step into a source that fits the target, though this represents a rather exceptional event. For example, a lightning during a storm offered Benjamin Franklin, who was investigating the nature of electricity, an analogical model to explain the sparks produced by an electric discharge of two close conductors. But chance, as suggested by the great biologist Louis Pasteur, “supports the prepared mind”. Though analogies are produced in an almost spontaneous way from our mind, their practice and elaboration may be of great help since they result in the activation of divergent and convergent procedures respectively depending on holistic and logic-rational strategies.[27)] Different modalities and strategies for selectively increasing the production of analogies have been therefore described.[25)]

§4. Implicit and explicit cognitive systems

As just indicated, one of the main characteristics of creative behaviour is the recombination of information in novel and potentially useful ways such as in analogical thinking. A critical approach to this cognitive strategy is therefore the study and description of underlying neural and cognitive systems.[28)]

From an evolutionary point of view, the brain has developed two different types of neural systems, each designed to deal with a different kind of information, emotional or cognitive. Despite the overlapping between these two informational systems, when these pathways reach the thalamus two distinct ways are followed: initial processing of emotional content occurs in various limbic system structures such as the amygdala while the next levels of affective processing take place in the cingulate cortex and the ventromedial prefrontal cortex. On the contrary, the cognitive system involves another set of limbic structures, primarily the hippocampal formation, and the temporal, occipital, and parietal cortices. It is generally agreed that this circuit is the site of long-term memory storage.[29),30)] Full integration of emotional and cognitive information depends on the fact that both types of computations, emotional and cognitive, converge back on the dorsolateral prefrontal cortex.[31)] This cortex is involved in executive processes and integrates the information in order to allow higher cognitive functions such abstract thinking, cognitive flexibility, planning, self-reflective consciousness.[32] It is also at the level of the dorsolateral prefrontal cortex that plans and strategies for appropriate behaviour are formulated and put to action through the motor cortices. Functions such as working memory,[33] temporal integration[34] and sustained and selective attention[35] also depend on this cortical area and allow complex cognitive functions to take place.

In addition to these two different types of knowledge (emotional or cognitive), there are two different systems involved in the acquisition, memorization and cognitive representation, the explicit and the implicit systems. The explicit system is rule-based and its content can be verbally expressed: in addition to that, it is tied to conscious awareness. The implicit system is skill or experience-based, its content can not be verbally expressed, but only through task performance, and it is inaccessible to conscious awareness.[36],[37] From a neural point of view, the explicit system is associated to the higher cognitive functions of the frontal and prefrontal lobes and medial temporal lobe structures. This system has evolved to increase cognitive flexibility. In contrast, the implicit system is associated to the skill-based knowledge supported primarily by the basal ganglia and has the advantage of being more efficient. The evolutionary origin of prefrontal cortex and of the explicit system is rather recent and therefore typical of those primates with a highly developed prefrontal cortex. This fact supports a hierarchical view of information processing where the most sophisticated mental abilities, and thus explicit knowledge representation, depend on the highest-order structure, the prefrontal cortex.[38] However, it would be simplifying to definitely separate explicit and implicit knowledge and the nervous structures upon which these two cognitive abilities depend. First, both systems may be activated in parallel.[39] Second, the striatum, one of the main structures of basal ganglia, is also involved in explicit cognitive functions and may be tuned with prefrontal cortex cognitive functions, also due to the complex connections associating the striatum to the frontal/prefrontal cortex. In addition, the striatum combines information from different cortical areas since their respective terminal fields converge.[40]

The function of ventral striatum emerges from a body of recent research indicating that the accumbens exerts a central role in behaviours, either positively or negatively reinforced.[41] Reinforcement may be concrete but also immaterial or virtual, mostly in human beings whose learning depends on internalized reinforcements such as parental or adult's approval of appropriate child behaviour. In addition to that, the accumbens, has a role in both procedural (implicit) and declarative (explicit) memories,[42] including those semantic memories which are mostly based upon language. The accumbens represents a key node of a network receiving critical (emotional) information from limbic structures such as the amygdala, from the mesencephalic nuclei involved in reinforced behaviours, from cognitive structures such as the hippocampus and the prefrontal cortex. This complex network, where the accumbens receives inputs and sends information to the other nuclei and cortical structures, explains the ideal position of this nucleus to elaborate and convert information in appropriate behavioural responses that may eventually be reinforced. In addition to that, the ventral striatum anticipates the rewarding outcomes of choices and signals the negative outcomes of those behaviours and decisions that are expected to be rewarded. It has been suggested that stimuli detected in a novel context or out of expected context activate the ventral striatum, as the basal ganglia monitor the reliability of predictions made in the prefrontal cortex.[43] Expectations may be cognitive as well as motor and since the chemical signals of the stress response are evoked by even mild dissonance such as discrepancies between perceptions and expectations,[44] it is reasonable, as suggested by Greenberg,[45] that the basal ganglia are deeply involved. The ventral striatum is also responsible for commuting from one task to another, depending on the needs of the moment. In other words, through this procedure it is possible to adapt a cognitive strategy to environmental requirements. Thus, the subcortical mechanisms of reinforcement, through their interaction with the frontal cortex and the emotional limbic and striatal systems, exert a key function in executive tasks such as planning, the selection of the appropriate action or, in other words, in decisional processes.

In summary, the hippocampus, temporal cortex and frontal structures are involved in learning new experiences, mostly based on explicit memory while the striatal system takes charge of the same information when it gets more known and recurs though time.[46] The circuits responsible for explicit and implicit cognitive functions (the hippocampus-cortex and the basal ganglia) may also act in parallel in many instances or take charge of the same task depending on factors such as novelty, practice, habits.

Having clarified the role of different brain structures in relation to implicit and explicit experiences, memory, learning and a number of executive functions we may proceed to an analysis of those neural changes that are associated to problem solving, flow (the mental state in which the person is fully immersed, typical of intense problem solving activities) and creativity in terms of primary and secondary processes.

§5. Primary and secondary processes of thought

It is well known that the brain frontal cortex undergoes different levels of activity or vigilance: sleepiness, for example, is associated to a low level of vigilance while playing a videogame or responding to sudden stimuli in short time requires high levels of cortical activation. The highest levels are reached in the course of emotions such as rage, fear etc. When learning is concerned, the optimal performance is reached at intermediate activation levels: while easy tasks are performed even at relatively high levels, complex tasks require lower levels. In other words, in order to perform an easy task we may be a little excited while to reach a higher concentration the brain must attain a lower activation level. During the transition from waking to reverie (open eyes dreams) and finally to full sleep the level of vigilance decreases: EEG waves become more and more slower while their voltage increases. Primary processes of thought –such as free associations and reverie-from which analogies and creative ideas might emerge– take place at intermediate levels of activation while secondary processes (in which cognition is abstract, logical and reality-oriented) involve attention and take place at levels of higher activation.[47] It has been suggested that prefrontal cortex activation leads to a block of “irrelevant” behaviours, a fact that increases purpose-oriented behaviour, such as problem solving, without paying attention to irrelevant mental associations.

Fromm[48] suggested that the primary process-secondary process continuum should be the main dimension along which cognition varies and proposed that creative individuals should be better able to alternate between these two thought dimensions than uncreative people.[49] According to this hypothesis, creative inspiration should involve a regression to a primary process state of consciousness. While primary process cognition is associative and should facilitate the discovery of new combinations of elements, creative elaboration should instead require the return to a secondary process state. Different data support the hypotheses that creative people have easier access to primary processes modes of thought.[50] For example, writing becomes more conventional and stereotyped in conditions of higher activation[51] and stress results in decreased originality when associative tests are performed.

In conclusion, the studies reviewed up to here imply that discovery of a solution (which is often improperly fully assimilated to creative behaviour) is characterized by the ability to commute from secondary to primary processes, thus letting emerge free associations and analogies. While one can agree on the fact that search of new solutions is related to an ability to switch off the prefrontal cortex, as to say to commute from secondary to primary thought processes, it seems less possible that what has been called a state of "hypofrontality"[52] or reduced prefrontal cortex activity leads to creativity. At this point a distinction should be done between flow, and creativity. As we will see, flow, the mental state in which the person is fully immersed in what he or she is doing, is typical of intense problem solving activities[53] and has been correlated to reduced prefrontal activity. Over creativity, flow has the advantage to allow different experimental approaches resulting in its measure and neural correlations. Creativity, on the contrary, is much more elusive and it is not easy to measure it. Thus flow has often been simplistically assimilated to creativity and it has been assumed that also creative activities depend on low prefrontal activity.

Thus, in the next section a distinction will be carried out between flow and creativity with the aim of differentiating the neural processes at the ground of these two mental functions.

§6. Flow and creativity

Flow is a mental state characterized by a feeling of energized focus, full involvement, and success in the process of the activity. Proposed by psychologist Mihaly Csikszentmihalyi,[53] the concept has been widely referenced across a variety of fields but has at its ground "an almost automatic, effortless, yet highly focused state of consciousness".[53]

A flow state ensues when one becomes so deeply focused on a task and follows it with such passion that everything else disappears. Flow is often associated to an euphoric state, in which the task is performed, without strain or effort, to the best of the person's ability. According to Csikszentmihalyi, any activity, mental or physical, can produce flow as long as it is a challenging task that demands intense concentration and commitment, contains clear goals, provides immediate feedback, and is perfectly matched to the person's skill level. The fact that people feel they operate without conscious thinking suggests that the prefrontal cortex is not an essential feature in flow processes and that flow may be considered as a fruit of implicit cognitive systems.[54)]

As previously noted, the explicit system is associated with the cognitive functions of the frontal lobe and medial temporal lobe and is responsible for increased cognitive flexibility. The implicit system is instead associated with the skill-based knowledge: it depends on basal ganglia and has the advantage of being more efficient. Thus, the flow state may be considered as a period during which a highly practiced skill or cognitive function that is already represented in the implicit system's knowledge base is realized without interference from the explicit system.[54)] The experience of flow may therefore be considered in terms of a state of transient lower activity of the prefrontal lobe that enables the temporary suppression of the analytical capacities of the explicit system.

In the course of flow, concentration is focused on a target, a fact that seems to challenge a state of decreased activity of the frontal lobe. Flow, in fact, demands attention to be directed and persistent, thus suggesting that the frontal attentional network should be active. However, focused attention is also a feature of other states of altered consciousness implying transient hypofrontality. In addition to that, people in a state of flow report a state that is consistent with decreased prefrontal function, such as the disappearance of self-consciousness and no distractions. Thus, flow is generally considered as a state of lower frontal activity with the notable exception of executive attention enabling the mind to be focused on a target by switching off other executive, cognitive abilities of the prefrontal cortex:[55),56)] focusing attention on the current task allows the implicit system to execute it at maximum skill level and efficiency. Creativity, on the contrary, emerges from the engagement of different brain circuits: novelty is first generated within the implicit system, namely the ventral striatum, and then analyzed by the prefrontal cortex that transforms novelty into creative responses and behaviours. As a matter of fact, it has been shown by different studies that the striatal implicit system reacts to novelty and generates novel responses in order to cope with environmental changes.[57)–59)] Brain imaging studies also show that in humans the striatum generates new and appropriate behaviours in response to changing situations.[60)] Subsequently, the prefrontal cortex takes charge of newly acquired behaviours but as they turn into repetitive practice are managed again by the basal ganglia, as to say transformed into implicit procedures.

Simonton[61)] equates creativity to a Darwinian process based upon the classic procedure variation-selection. In this regard, the basal ganglia, with their implicit strategies and memories, may be regarded as an mechanism that continuously produces novelty[62)] while the prefrontal cortex, possibly its dorsolateral areas, is the computational mechanism that transforms novelty into creative behaviours. Thus, the rich associative network that allows the striatum to merge motivational, emotional and cognitive information from different cortical areas and to relay it to the prefrontal cortex represents a generative tool that can explain the creative explorative behaviour of non-human primates, the transformation of play motor and exploratory experiences into cognitive patterns and the production of analogies at the ground of creative discoveries and approaches.

In conclusion, as our knowledge of the brain increases, it is more and more evident that a cognitive function often depends on a multiplicity and redundancy of mechanisms instead on a single structure or system. For example, language does not exclusively stem from motor and sensory areas on the left hemisphere but also from the networks connecting these areas to the basal ganglia.[63] Similarly, the analysis of creativity shows that a plurality of structures and functions are implicated in its occurrence and that the traditional duality between right and left hemispheric functions cannot per se explain creative behaviours. While many theories of creativity still adhere to this simplistic view, it is today evident that this faculty must be considered within the framework of its several relationships with our neural and cognitive processes such as implicit and explicit strategies, primary and secondary states of mind, executive abilities, purpose-oriented behaviours and emotionality. In addition to that, creativity may also be regarded from a more general point of view, as to say in terms of those plastic processes that allow to cope with the environment and to adapt to it through new, original strategies: in evolutionary terms these processes involve the passage from specialized, stereotyped behaviours to generalist approaches and to novelty-seeking behaviour. As a consequence of these multifaceted relations between brain and creativity we should keep in mind that inventive and original attitudes may be enhanced during infancy by encouraging a multiplicity of activities which are the preconditions of creative behaviours, such as free and social play, analogical thinking, focused attention.[64]

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