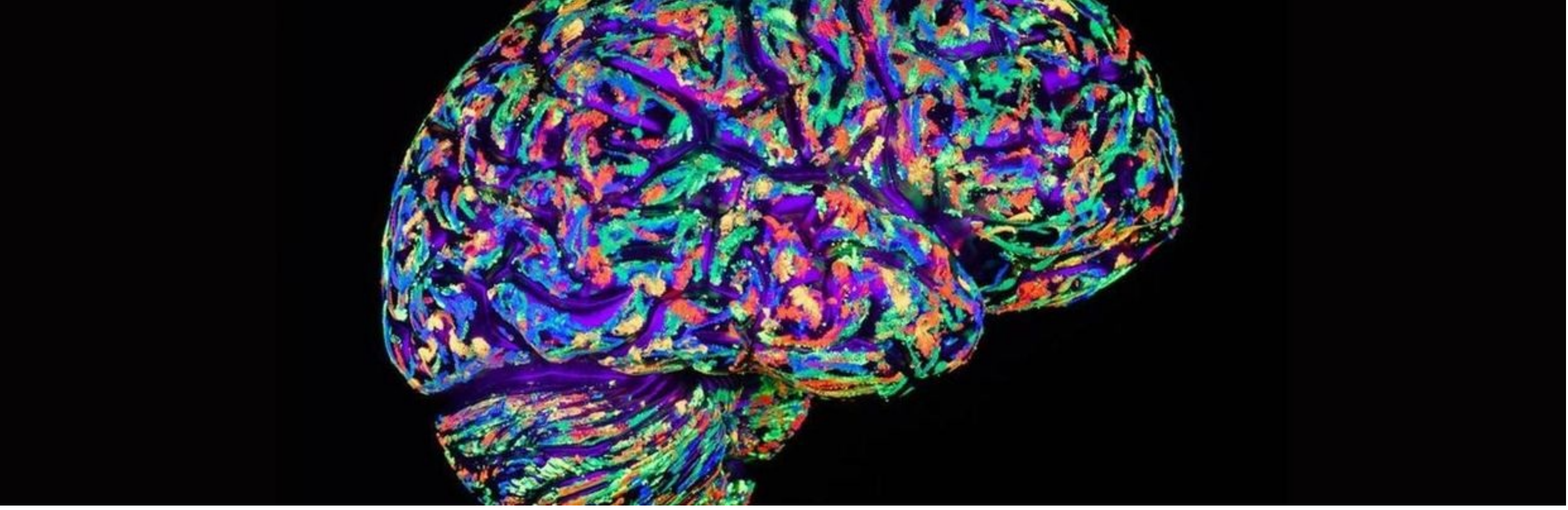

Photography and the Visual Brain

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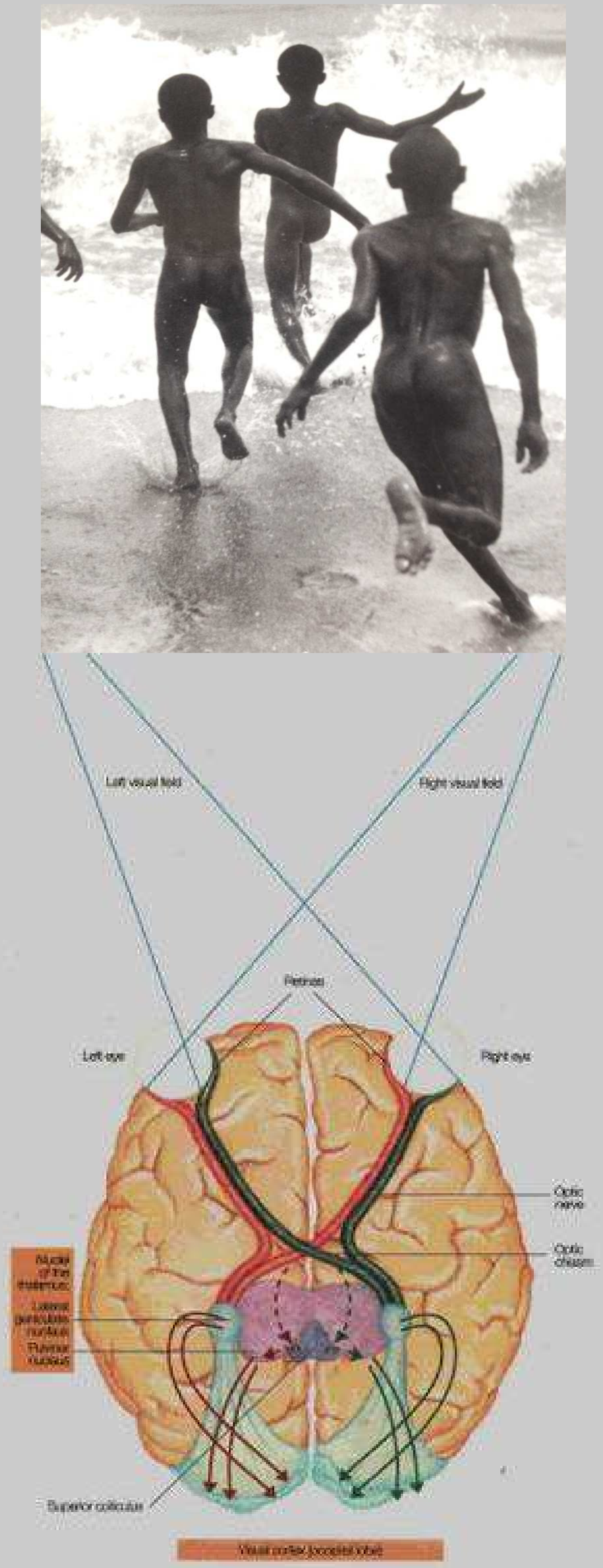


“Voire c’est déja une operation créatrice, qui exige un effort”

Henry Matisse

Chiara Salabe`

University of Freiburg - Faculty of Medicine (April 2012)
Neuroscience: Prof. Haverkampf

Picture on coverpage: *Three boys at Lake Tanganyika*, Martin Munkacsi (1930)

Table of Contents

I. ***INTRODUCTION***[1]

Art is a broad field which is mostly studied from the point of view of its final products, i.e. what is the message of the artist, which the technique, how does his/her work locate into its epoch and how in regard to the history of that specific art. Whichever angle is taken as a reference point, the artist is always considered as the unit of analysis together with its artistic expression. This short essay has the aim to look at a specific part of the artist's body which ultimately enables – whether in conception, or in execution or in appreciation – expression of art: the visual brain.

Of all forms of artistic expression, among which painting, sculpture, music, this work wants to focus on one very specific: photography. The choice of photography is motivated on the one hand by personal interest and experience in the field, on the other hand by two important links with the visual brain. Firstly, the choice to take a shot and capture in a fraction of a second a moment of reality is the result of a number of neuronal pathways where the camera could almost be considered as an extension of the brain. Second, there is a strong parallel between the function of photography and the function of the brain, which is the "acquisition of knowledge about the world". Photography has the aim to provide knowledge about the world we live in seizing from the continually changing information one unique moment which expresses the reality (of the artist). Also the brain must discount a great deal of the information which is not essential to its aim of representing the true character of objects. As written by Zeki[2]: "The brain extracts from the continually changing information reaching it only that which is necessary for it to identify the characteristic properties of what it views;…Vision, in brief, is an active process depending as much upon the operations of the brain as upon the external, physical, environment; the brain must discount much of the information reaching it, select from that information only that which is necessary for it to be able to obtain knowledge about the visual world and compare the selected information with its stored record of all that it has seen".

This essay describes the pathways of the brain preceding a camera shot, from the external sensory stimulus, to the elaboration in the neocortex, and finally to the response in the motor action represented by the "click". The focus will be on the visual brain; we will see how it is characterized by a set of parallel processing of perceptual stimuli as well as temporal hierarchical awareness of perception. We will also briefly describe how the elaboration of the external stimulus is transferred into motor action, which in the case of photography is able to

[1] This essay is based – unless otherwise specified – on Eric Kandel, James Schwartz and Thomas Jessell, *Principles of Neural Science*, McGraw-Hill Medical (2000).
[2] Semir Zeki, *Art and the Brain*, Daedlus 127, No. 2, p. 71-102 (1998).

capture the essential feature of a specific reality in a fraction of a second. Other brain areas integrated in such processing will be listed.

The underlying question of this work, or better red thread, is in fact to try and describe what exactly enables an artist/photographer's mind to capture exactly that fraction of a second which fixes a certain truth about the world we live in. Henri Cartier-Bresson wrote about a picture of Martin Munkacsi represented in the cover of this essay:"I suddenly understood that photography can fix eternity in a moment. It is the only photo that influenced me. There is such an intensity in this image, such spontaneity, such *joie de vivre*, such miraculousness, that even today it still bowls me over. The perfection of form, the sense of life, a thrill you can't match".[3]

The photograph is about three naked black youth, seen from the rear, plunging into the waves of Lake Tanganyika in Africa. That picture has many striking elements among which the most powerful the movement, youth, energy and speed of the boys which expresses nothing, but life. Such picture exists first in the brain before it is transformed into its "paper" version and this short paper describes how this occurs through an interaction of complex parallel and hierarchical cerebral processes. It is mainly, but not only, a product of the visual brain and the camera becomes an extension of the body. Pierre Assouline[4] writes about Cartier-Bresson's relationship to his Leica: "Like lovers, each complemented the other. By extending his vision in the most natural manner possible, the camera was indeed part of him."

II. *THE VISUAL BRAIN*

2.1 The anatomy of visual pathways

2.1.1 Location of the main structures

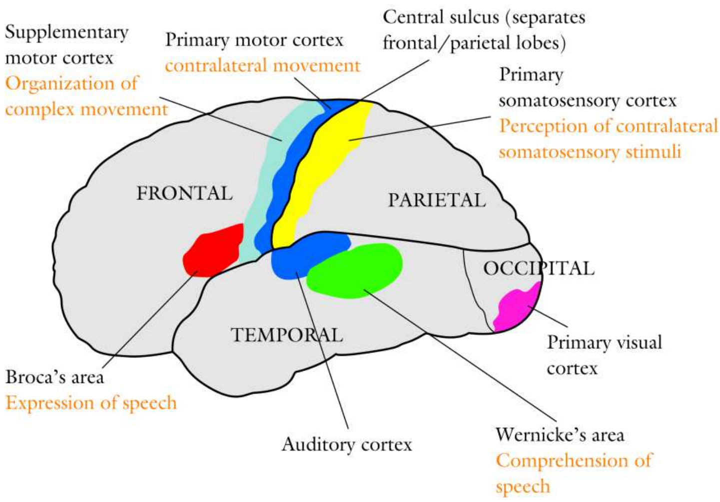
For many years research in neural science has been devoted to understanding whether mental processes are localized to specific regions of the brain, or whether the mind represents a collective and emergent property of the whole brain. It is now peaceful in neuroscience that different regions of the brain are specialized for different functions, even though many sensory, motor and cognitive functions are served by more than one neural pathway.

[3] Pierre Assouline, *Henry Cartier-Bresson. A Biography*, Thames & Hudson, p. 61 (2005).
[4] See footnote 3.

The brain activity responsible for our cognitive abilities occurs primarily in the cerebral cortex, the gray matter in both hemispheres. The cortex is divided into four different lobes which have specialized functions. The frontal lobe deals with planning of future action and with the control of movement, the parietal lobe with somatic sensation, with forming a body image and its relation to one's extrapersonal space, the temporal lobe with hearing and the occipital lobe with vision. The deep structures of the brain – hippocampus, amygdala and basal ganglia – are concerned with aspects of learning, voluntary motor control, memory and emotion (Fig. 1).

The visual brain is composed of many different elements in the brain and its importance for the aim of this short essay is given not only its direct link to the act of photography, but also by its overall significance in the brain. Through research on monkeys, whose visual capacities are similar to the ones of the humans, it has been discovered that over 50 percent of the cortex is devoted to processing visual information.

Fig. 1 – The lobes of the cortex

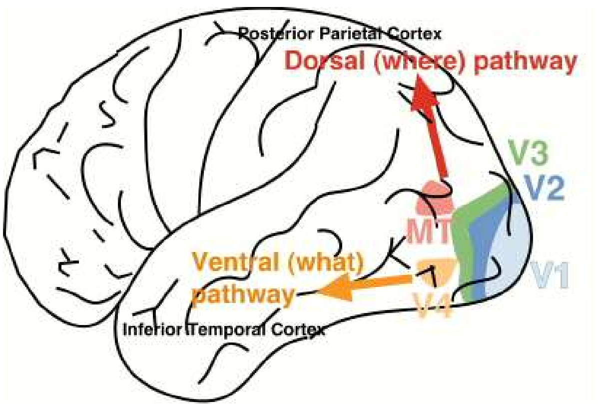


Many areas in the cerebral cortex are concerned primarily with processing sensory information or delivery of motor commands. Each area includes several specialized sub-areas that have different functions for information processing which are known as primary, secondary or tertiary sensory/motor areas depending on their proximity to the peripheral pathways. In the motor pathways *primary* is related to the fact that it contains neurons that project directly to the spinal cord to activate somatic motor neurons, in the sensory system *primary* areas receive information directly from the thalamus. Each primary sensory area conveys information to higher-order area, which refines the information for a single sensory modality. Higher-order outputs are sent to one or another of three major multimodal association areas (see chapter 2.3.4) that integrate information from more sensory modalities.

The primary visual cortex is located caudally in the occipital lobe and is associated with the calcarine sulcus. In very general terms the visual pathway goes from the eye through part of the diencephalon to end in the occipital cortex. The main stations are the retina with its three neurons, the optic nerve, the optic chiasma, the optic tract, the lateral geniculate nucleus, the optic radiation and the area striata (primary visual cortex or V1). In particular, the photoreceptors of the retina (also called first neuron) project onto the bipolar cells (second neuron), which then connect through synapses with the retinal ganglion cells (third neuron). The axons of the latter form the optic nerve, which projects to the lateral geniculate nucleus in the thalamus; from there the path ends in the primary visual cortex located in the occipital lobe (Brodmann's area 17 or V1/striate cortex). Next to the striate is the extrastriate cortex, a set of higher-order visual areas containing also representations of the retina (Brodman areas 18-19 or V2-V5). Each extrastriate area is specialized for processing a different part of visual information, i.e. motion, form and color, and cells in different areas have different properties (Fig. 2).

Extrastriate visual areas are organized into two pathways: a dorsal pathway from V1 to the posterior parietal cortex (including the middle temporal area V5) and a ventral pathway extending from V1 to the inferior temporal cortex, including area V4. On the basis of deficit resulting from lesions it was suggested that the former pathway transmits information about *where* objects are, the latter pathway about *what* objects are. An analog parallel division is found also in the connections between the retina and the cortex where at least two major pathways can be identified on the basis of two different types of cells (large M cells and small P cells) initiating the information processing. The visual system is thus organized into well-defined parallel pathways extending from the retina into parietal and temporal lobes, rather than only serial and hierarchical processing.

Fig. 2 – The striate and extrastriate cortex



The organization of the visual cortex shows additional stratifications. Like in other parts of the cortex, the striate cortex is organized into narrow columns of cells, going from the pial surface to the white matter. Columns in the visual system seem to be organized to allow local interconnections of cells, which allow a new level of abstraction of visual information. There are three major vertically oriented systems crossing the layers of the primary visual cortex: orientation columns, blobs (peg-shaped patches in upper layers concerned with color) and ocular dominance columns, which receive inputs from one or the other eye. These vertical systems consisting of functional columns spanning the different cortical layers, communicate with each other by means of horizontal connections that link cells within a layer and integrate information over many millimeters of cortex. This means that a cell can be influenced by stimuli outside its normal receptive field.

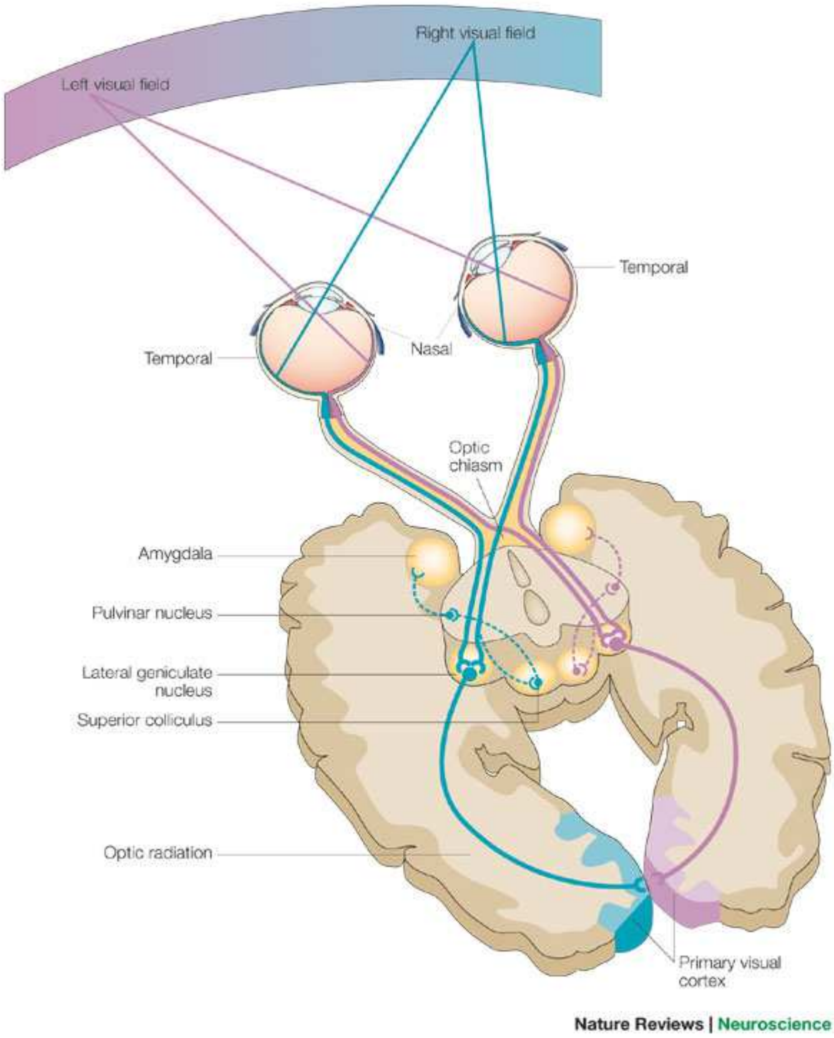
This stratification allows the primary visual cortex to elaborate information in three different ways. Firstly, each part of the visual field is decomposed into short line segments of different orientation, through orientation columns; this step is necessary for discrimination of form. Secondly, color processing occurs in cells that lack orientation selectivity, the so-called blobs. Thirdly, the input from the two eyes is combined through the ocular dominance columns, necessary for perception of depth. Neurons with similar response properties in different vertically oriented systems are linked by horizontal connections. Information thus flows between layers and horizontally through each layer. As a result the visual system is connected to a number of different regions of the brain as we will see with more detail in 2.3.

2.1.2 Peripheral and central pathways

The image recorded by the retina is an inversion of the visual field. The retina is divided in two perceptive fields, the nasal hemiretina which lies medial to the fovea, and the temporal hemiretina lateral to the fovea. The visual field is what the eyes see without head movement and has both binocular and monocular zones. In particular, the left side projects onto the nasal hemiretina of the left eye and the temporal hemiretina of the right eye, whereas the right field projects onto the nasal hemiretina of the right eye and the temporal hemiretina of the left eye. While each optic nerve carries all the visual information from one eye, each optic tract carries only a representation of one half of the binocular zone in the visual field (Fig. 3).

The ganglion cell’s axons (third neuron in the retina) extend through the optic chiasm. While fibers of the nasal side of each retina cross to the contralateral hemisphere, the ones in the temporal hemiretina do not and stay ipsilateral. As a result axons from the left half of each retina project in the left optic tract, which carries a complete representation of the right hemifield of vision. Similarly, the right half of each retina projects in the right optic tract, which guides information from the left hemifield of vision. The two optic tracts project to three major subcortical stations: the pretectum, the superior colliculus, and the lateral geniculate nucleus (Fig. 3).

Fig. 3 – Visual pathways



We have seen that a division of parallel pathways can be found between the primary and extrastriate visual cortex. Similarly, connections between the retina and the primary visual cortex convey parallel pathways. On the one hand there are M ganglion cells which project to the magnocellular layers of the lateral geniculate nucleus, on the other hand P ganglion cells which project to the parvocellular layers. Both then connect to different layers of the primary visual cortex. These two pathways have shown a key difference as regards their sensitivity to color contrast: the P cells respond to changes in color (red/green and blue/yellow) regardless of the relative brightness of the color, whereas M cells respond weakly to changes of color when the brightness of color is matched. The M and P cells differ also in regard to luminance contrast (higher for M cells), spatial frequency (higher for P cells) and temporal frequency (higher for M cells).

Along the pathway each cell level further away from the initial receptors has a greater capacity for abstraction than cells at lower levels. At each level of the afferent pathway the stimulus properties that activate a cell become more specific. In fact, retinal ganglion and geniculate neurons respond primarily to contrast. This information is transformed in the cortex into relatively precise line segments and boundaries, suggesting that contour information may be sufficient to recognize an object. As David Hubel writes: “Many people, including myself, still have trouble accepting the idea that the interior of a form ...does not itself excite cells in our brain…that our awareness of the interior as black or white…depends only on cells’ sensitivity to the borders.”[5]

2.2 The physiology of visual pathways

2.2.1 Hyperpolarization

All senses share a common trajectory of general steps: a physical stimulus, a number of processes which transforms the stimulus into nerve impulses and a response to this impulse in the form of a perception or conscious experience of sensation. Colors, tones, smells and tastes are mental creations constructed by the brain out of sensory experience. This section describes how a visual stimulus is transformed into conscious awareness.

Receptors and neuronal pathways to the target areas in the brain, comprise a system which provokes specific types of sensations such as touch, taste, vision and hearing. Receptors are distributed in a sense organ. In the case of the visual system they are located in the retina through its photoreceptors, represented by rods and cones cells. These sensory receptors transform stimulus energy into electrical energy, thus establishing a common mechanism in all sensory systems.

There are four classes of receptors depending on the physical energy they are sensitive to, namely mechanical, chemical, thermal and electromagnetic. Whereas for the other energies we can find more receptors, for the electromagnetic energy humans posses only one type of receptor: the photoreceptor of the retina.

[5] David H. Hubel, *Binocular interaction in striate cortex of kittens reared with artificial squint*, Journal of Neurophisiology, N. 28, p. 1041-1059 (1965).

Light represents the external stimulus and is captured by the cornea and the lens, then traverses the vitreous humor before reaching the photoreceptors in the retina. To impede that photoreceptors are absorbed or greatly scattered, the axons of neurons in the proximal layers of the retina are unmyelinated so that these layers are relatively transparent. The photoreceptors are of two kinds, *rods*, enabling night vision, and *cones* responsible for day vision. Cones perform better than rods in all visual tasks except the detection of dim stimuli (Tab. 1).

Table 1 - Differences Between Rods and Cones and Their Neural Systems

Rods	***Cones***
High sensitivity to light, specialized for night vision	Lower sensitivity, specialized for day vision
More photopigment, capture more light	Less photopigment
High amplification, single photon detection	Lower amplification
Low temporal resolution: slow response, long integration time	High temporal resolution: fast response, short integration time
More sensitive to scattered light	Most sensitive to direct axial rays
Rod system	***Cone system***
Low acuity: not present in central fovea, highly convergent retinal pathways	High acuity: concentrated in fovea, dispersed retinal pathways
Achromatic: one type of rod pigment	Chromatic: three types of cones, each with a distinct pigment that is most sensitive to a different part of the visible light spectrum

Source: Kandel E.R., Schwartz J.H, Jessel T.M. (2000)

The absorption of light by visual pigments in rods and cones triggers a cascade of events that leads to a number of subsequent reactions that provoke a change in ionic fluxes across the plasma membrane of the cells, and consequently a change in membrane potential. A key molecule in the cascade is the nucleotide cyclic guanosine 3’-5’ monophosphate (cGMP). Light activates visual pigments which activate cGMP phosphodiesterase (enzyme which reduces the concentration of cGMP in the cytoplasm) which then induces the closing of the cGMP-gated channles. As a result photoreceptors are hyperpolarized.

The mechanism to translate stimulus energy into receptor potential varies with the type of physical stimuli. In the case of chemoreceptors and photoreceptors, receptor potentials are generated by intracellular second messengers activated when the stimulus agent binds to membrane potentials coupled to G proteins. Chemoreceptors respond to the appropriate ligand with a depolarizing potential, whereas photoreceptors respond to light with hyperpolarization. The great advantage of the second messenger mechanism is that the sensory signal is amplified.

The visual information is finally transferred from cones to ganglion cells along two types of pathways in the retina. Cones in the center of a cell's receptive field make direct synaptic contact with bipolar cells that connect with the ganglion cells. Signals in the rest of the cell's receptive field also come from bipolar cells, but only indirectly through horizontal and some amacrine cells. The former are called vertical or direct pathways, the latter lateral pathways.

Signals from photoreceptors to ganglion-cells are transmitted in parallel in the center and outside the centre of the cell. An on-center ganglion cell is exited when light stimulates the center of the receptive field and inhibited when light reaches its surrounding area. The opposite responses apply to off-center ganglion cells. This mechanism enables higher processing areas in the visual brain to detect weak contrasts and rapid changes in light intensity. In addition, ganglion cells are specialized for conveying information about the visual image such as movement, fine spatial detail and color. Here again we can see that in the visual system the division of information processing into parallel processing pathways, including lateral connection, starts at the level of the sensory cell to be perpetuatted all the way to the striate and then extrastriate cortex.

2.2.2 The stimulus and its qualities

Each of the receptors modality has several qualities: in the case of taste for example these are sweet, sour, salty or bitter; with objects we can distinguish color, shape and movement. Under normal circumstances a receptor is sensitive only to one type of stimulus (light in the case of the photoreceptors in the retina), however, if a stimulus is strong enough it can activate several kind of nerve fibers (photoreceptors will respond to a blow to the eye despite being insensitive to mechanical stimulation). Moreover, each class of receptors is not homogenous but instead contains a variety of specialized receptors that respond to a limited range of stimulus energy. As a result, individual photoreceptors do not respond equally to all wavelengths but to only a small part of the spectrum.

The spatial resolution of a stimulus is determined by its receptive field and responds only to stimulation within it. The density of receptors in a given part of the body determines how well the sensory system can resolve the detail of stimuli in that area: a denser population of receptors leads to a finer resolution of spatial detail because the receptors have smaller receptive fields. The identity of a sensory neuron is not only defined by the modality of a stimulus, but also by the place it occurs. The intensity and duration of a stimulus are dependent by the amplitude and time course of the receptor potential and by the total number of receptors activated. In the brain intensity is related to the strength of the stimulus which determines the frequency of firing in an action potential. The final conscious output in the central nervous system depends on parallel information flows about the complex qualities of sound, visual images, shapes, textures, tastes and odors which are there integrated to achieve a round and full perception of the real world.

2.3 Integration of information

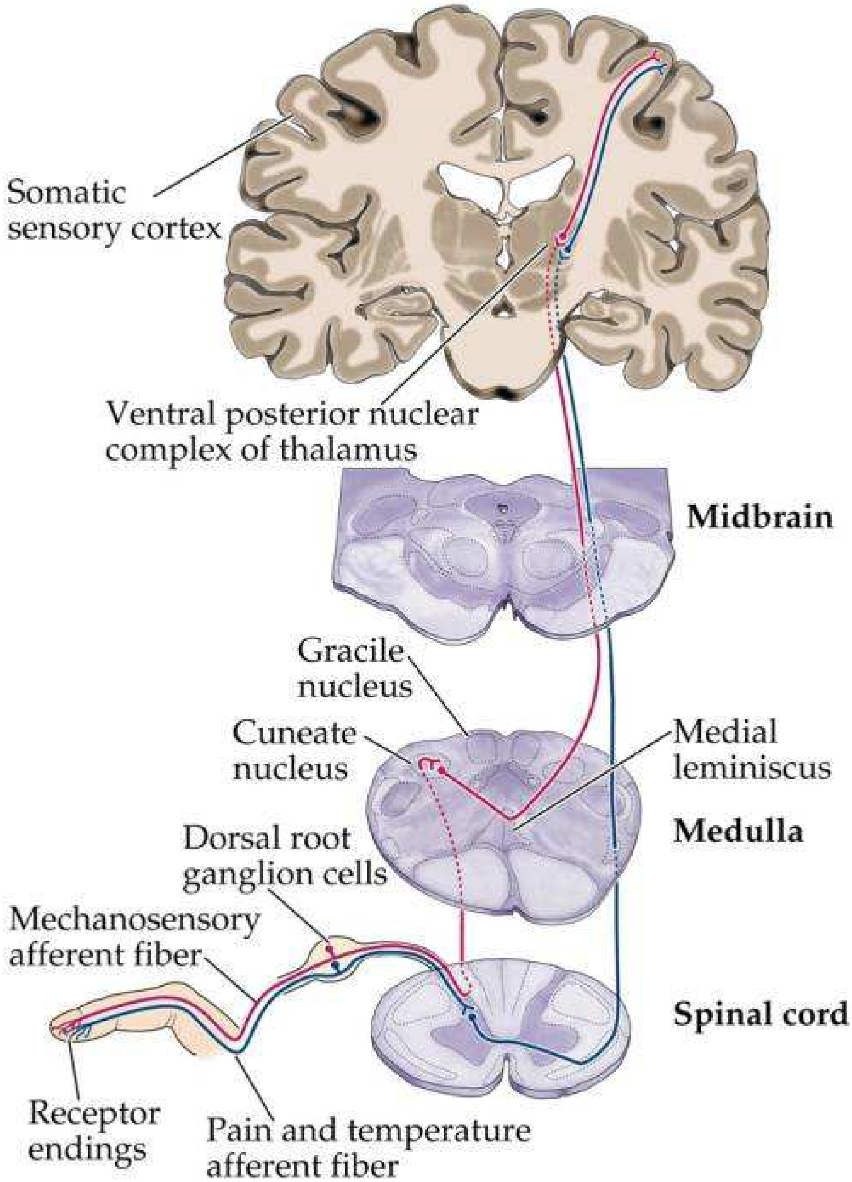
2.3.1 Ascending and descending pathways

Sensory information from the trunk and limbs reaches the spinal cord, which is composed of an H-shaped gray matter core with each side subdivided into dorsal and ventral horns. The gray matter of the dorsal horn contains the sensory nuclei, whose axons receive stimuli from the body's surface. The ventral horn contains the motor nuclei, whose axons exit the spinal cord and reach the skeletal muscles. The motor cells do not form clusters like the sensory nuclei, but are instead arranged in columns that run along the length of the spinal cord. Interneurons of various types modulate information flowing from sensory neurons to the brain and the commands from higher centers in the brain to the motor neurons, as well as information passed between groups of motor neurons.

The white matter surrounding the gray matter is divided into dorsal, lateral and ventral columns, which contain bundles of ascending or descending axons. The dorsal columns lead only ascending axons that carry somatic sensory information to the brain stem, the lateral include both ascending and descending paths, the latter from the brain stem and neocortex that innervate interneurons and motor neurons in the spinal cord. The ventral columns also include both paths, where the ascending axons convey in parallel with lateral ones information about pain and thermal sensation to higher level of the central nervous system. The descending ventral motor axons control axial muscles and posture.

The sensory neurons that transport information from the skin, muscles and joints of the limb and trunk to the spinal cord are clustered together in dorsal root ganglia within the vertebral column immediately adjacent to the spinal cord. These neurons are pseudounipolar neurons with split axons into central and peripheral branches. Some local branches end in the spinal cord, while ascending branches connect with higher level centers. The local branches can activate local reflexes circuits while the ascending branches carry information into the brain about perception of touch, position sense or pain (Fig. 4).

Fig.4 – Sensory pathways



2.3.2 Brain areas dealing with emotions and memory

Emotions involve patterns of autonomic activity and hormonal and cortical responses. The integration of these different inputs takes place in the amygdala, whose connections to the neocortex are either direct or indirect through the thalamus to the orbito-frontal and the prefrontal cortex. The left amygdale is preferentially involved in processing conscious emotional information, whereas the right processes non-conscious information.[6] Different emotions constitute different activation patterns in the brain. The central nucleus of the amygdale is important for expressing fear, whereas the anterior cingulate cortex of the limbic system is activated during irritation and anger.

The right hemisphere is better than the left in the expression of emotions and in the recognition of emotions in facial expression. Emotions are predominantly processed in the right hemisphere, especially negative emotions like sadness and fear. Arousal of the right frontal region is associated with emotions involving reflective awareness, depression and withdrawal, whereas on the left side it is associated with alert expectation and approach.

Memory is an associative function and involves the formation and activation of different areas of cortical networks. Perceptual memory is based on the three hierarchical levels of perceptual knowledge gained through sensory processing and stored in the posterior cortex. The recall of perceptual memories involves ventral and dorsal streams for the two types of visual information.

Executive memory is stored in the frontal cortex. The prefrontal cortex performs the integrative functions of working memory, attention and inhibition. Motor memories of concrete and stereotypical sequences of actions are stored in the basal ganglia. Long-term or declarative memories involve two brain areas: the right hippocampus and the right prefrontal cortex.

The integration of sensory information and formation of declarative memories take place in the hippocampus, which is active in the formation of long-term memories but does not store them. It receives and processes information from the sensory association areas in the parietal lobe as well as from the amygdala, basal ganglia and other subcortical areas. In this process the hippocampus forms associations between the representations and sends them back to the association cortex, where the memories are consolidated and modified.

Speech production involves Broca's area in the inferior left frontal lobe whereas speech comprehension and recognition of words are located in the Wernicke's area. The posterior language area surrounding the Wernicke's area interfaces with the perceptions and memories stored in the sensory association cortex and thus contributing to the meaning of words. Finally, mental images share the same pathways and brain areas for their formation and processing as do perceptions in the different sense modalities.[7]

[6] Diego Pizzagalli, Alexander J. Shackman and Richard J. Davidson, The functional neuroimaging in human emotion: Asymmetrical contributions of cortical and subcortical circuitry, in K. Hughdahl & R.J. Davidson (Eds.) The asymmetrical brain, p. 511-532, MIT Press (2003).

[7] Vija B. Lusebrink, Art therapy and the brain: An attempt to understand the underlying processes of art expression in therapy, Journal of the American Art Therapy Association, N. 21(3), p.125-135 (2004).

2.3.3 Connecting sensory and motor information

The thalamus is a key structure in connecting sensory information with cortex areas. It is an oval-shaped center that constitutes the dorsal portion of the diencephalon. It conveys sensory input to the primary sensory areas of the cerebral cortex and at the same time acts as a filter modulating the passage of information. It is made of well defined nuclei grouped in four areas – anterior, medial, ventrolateral and posterior – where the lateral geniculate nucleus is in the posterior area and receives, as mentioned, information from the retina.

The thalamus not only projects to the visual areas but also receives a return projection from the neocortex. A major function of the sensory system is to provide the perceptive information necessary for actions mediated by the motor system in the brain and spinal cord. This occurs mainly in the corticospinal tract which leads for almost half of its axons information from the motor cortex. Such descending tract is also called pyramidal tract and crosses, like the ascending somatosensory system, to the opposite side of the spinal cord (at the so-called pyramidal ducussation in the medulla). This tract makes monosynaptic connections with motor neurons, very important for individuated finger movements. It also forms synapses with interneurons in the spinal cord, which are important for coordinating groups of muscles when reaching or walking.

The motor information which goes through the corticospinal tract is modulated by sensory information and other motor regions providing a mix of inhibitory and excitatory signals. This includes a continuous flow of tactile, visual and proprioceptive information needed to make voluntary movement both accurate and properly sequenced. In addition, the output of the motor cortex is impacted also by other motor regions of the brain, including the cerebellum and the basal ganglia, that provide the information for smoothly executed movements.

The basal ganglia receive direct projections from much of the neocortex, including sensory information and information about movement, whereas the cerebellum receives somatosensoric information directly from spinal ascending tracts, as well as from the neocortex descending tract. The cerebellum can influence posture and movement through its path through the nucleus ruber, which can modulate directly descending connections to the brain stem and the spinal cord. However, the major influence of the cerebellum on movement is through its connections to the ventral nuclear group of the thalamus, which is directly related to the motor cortex.

We see that sensory and motor information are processed in the brain in a variety of pathways that are active simultaneously and all follow pattern of hierarchical and parallel processing depending on the pathway. Perceptions and sensations are not precise copies of the world around us, but rather an abstraction. As Amaral writes: "The brain constructs and internal representation of external physical events after first analyzing various features of those events. When we hold an object in the hand, the shape, movement, and texture of the object are simultaneously but separately analyzed according to the brain's own rules and the results are integrated in a conscious experience." [8]

2.3.4 The binding problem

We shall now see how the depicted integration occurs, the so called *binding* problem. As we know, mental functions are localized to specific areas of the brain, but complex mental functions require integration from several cortical areas. For that purpose the brain has higher-order areas of cortex that are neither sensitive, nor motor, but associative.

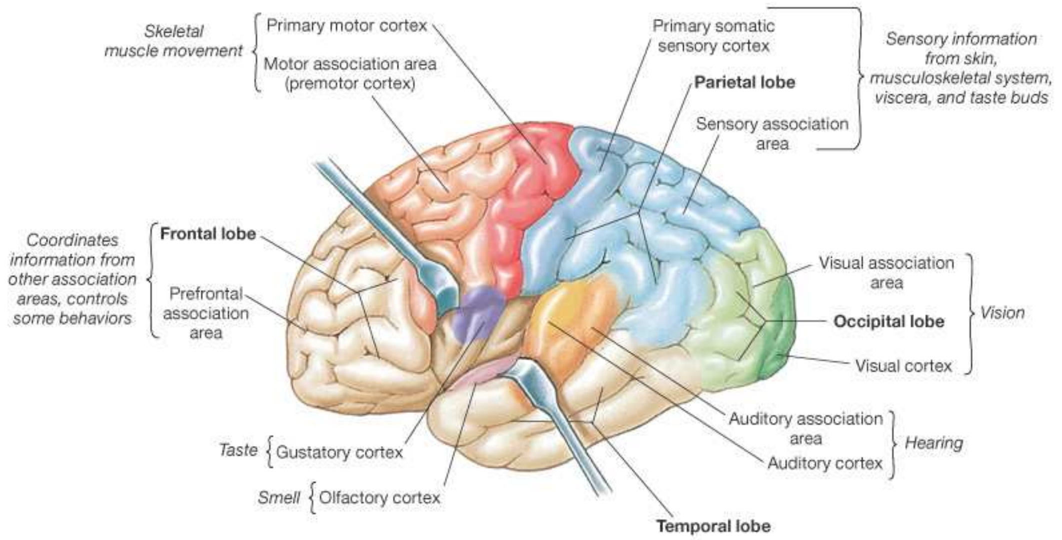
These associative areas associate sensory inputs to motor response, which is what occurs when taking a photograph. Each primary sensory cortex projects to nearby higher-order areas, called unimodal association areas that integrate afferent information for a single sensory modality. The visual association cortex integrates for example information about form, color and motion that arrive to the brain in separate pathways. Unimodal association areas then project to multimodal sensory association areas that integrate information about more than one sensory modality. Finally, the latter send information to the multimodal motor association areas, which transform sensory information into planned movement and further through the premotor and primary motor cortex into implementation of motor action.

The posterior association area (parietal, temporal and occipital lobe) connects information from the several sensory modalities for perception and language. The limbic association area (medial edge of the cerebral hemisphere) deals with emotion and memory. The anterior association area (prefrontal cortex, rostral to postcentral gyrus) is concerned with planning movement (Fig.5).

[8] David G. Amaral, *The functional organization of perception and movement*, in Eric Kandel, James Schwartz and Thomas Jessell, *Principles of Neural Science*, McGraw-Hill Medical, p.348, (2000).

Three important principles govern the functioning of the association areas. Firstly, information is processed in a series of hubs along parallel pathways from peripheral receptors through primary sensory cortex and unimodal association areas to the posterior multimodal association areas. Secondly, information representing different modalities converges upon areas of the cortex that integrate them. Thirdly, the posterior association areas that process sensory information are highly interconnected with the frontal association areas responsible for planning motor action.

Fig. 5 – Association areas



The result of all these connections is some kind of comprehensive experience often called "consciousness". As written by Kandel: "The unity of consciousness – our continuous and connected experience of events – must depend on the brain's ability to link discrete spatial or temporal events into a single experience. Besides its unitary nature, consciousness has many components among which subjectivity, intentionally and a more tractable and well-defined component such as selective attention. Of all the ever changing world around us only a small fraction of sensory stimuli leaves an impact."[9]

Already William James in 1890 had pointed out that selective focusing of the sensory apparatus on one element out of many is an essential feature of all sensory processing. The importance of selective attention has been further examined by a number of researchers among which Robert Wurtz and Michael Goldberg[10]: like neurons in other visual areas, parietal neurons respond to the presence of a visual stimulus in the receptive field; however,

[9] Eric Kandel, *From nerve cells to cognition: The internal cellular representation required for perception and action*, in Eric Kandel, James Schwartz and Thomas Jessell, *Principles of Neural Science*, McGraw-Hill Medical, p.402, (2000).
[10] Robert H. Wurtz and Michael E. Goldberg, *Brain mechanisms of visual attention*, Scientific American, N. 246(6), p.124-135 (1982).

their research indicate that the strength of this response depends on whether the animal is paying attention to the stimulus. When the monkey has to attend to the stimulus, the same retinal input elicits a much larger response. The increased firing of neurons happens independently to the reaction of the animal, i.e. whether it merely looks at the stimulus or reaches toward it. This indicates that the enhancement of neuronal activity is a result of attention rather than of the preparation of a motor response.

Research has also shown that selective attention enhances the response of neurons in many brain areas and especially throughout the visual system. This evidence suggests that selective attention sharpens our sensory machinery, which is also an advantage in the planning of movement. Van Hullen and Koch[11] argue that attention, in a very general sense, can be seen as a set of processing mechanisms and strategies designed to overcome the processing of failures or confusion when inserted into the real world where visual stimuli can be either unfamiliar, or plagued by external noise and low contrast. In other words competition between candidate neuronal representations often limits a correct visual processing of reality and attention can act by biasing the competition stimuli to mactching the input to one or more stored representation.

III. *THE INTERACTION OF ART AND COGNITION*

As mentioned in the introduction of this work arts and the visual brain can be associated for their functional identities, as producer of knowledge about the ever changing world. In such role both should provide the human being with some sort of guidance in its normal living activities, as far as the visual capacities are concerned, and with judgment when dealing with the subjectivity of one's perception about the reality surrounding us, as far as arts is concerned. Besides this functional closeness art and brain are related also from an educational and brain performance point of view. While, nerve cells are wired together in a precise and orderly manner which does not vary significantly between individuals, connections are not the same in all individuals and can be altered and shaped by certain activities and learning. This section provides a brief description on how artistic activity can influence and shape a number of cognitive activities. The presented literature does not focus on photography but on art in general.

Some pieces of research have developed a theory about how arts training works in the brain and its possible positive effects. There seems to be specific brain networks for different

[11] Rufin Van Hullen and Christof Koch, *Visual attention and visual awareness,* in Gastone G. Celesia (Eds.), *Handbook of Clinical Neurophysiology, Vol V: Disorders of Visual Processing,* Elsevier, p. 65-83 (2005).

art forms and a general factor of openness to the arts. Moreover, it has been found that children with high interests and training in arts, develop high motivation, which in turn sustains attention. High sustained attention improves cognition.[12]

The importance of attention becomes very clear when considering the complexity of connections in the brain and between its structures. As we have already seen the cerebral cortex is in very broad terms divided into two parts: the frontal or executive cortex and the posterior or perceptual cortex. The frontal cortex incorporates the prefrontal and primary motor cortex, whereas the posterior cortex consists of several areas that process sensory and perceptual information. The path goes from the primary sensory cortex (elementary feature of perception), to the unimodal association cortex (analysis of input for a specific modality) and finally to the multimodal association cortex (integration of perception across various sensory and non-sensory modalities). As stated by Fuster most of the perceptual stimuli are processed in parallel and unconsciously and the conscious part of perceptual processing "is guided by selective attention, a top down cognitive function that, like memory, determines the course of categorization".[13]

Another group of researchers looked at the interactions between art and cognitive performance, by investigating how aesthetic ability and arts education correlate with improvements in children's reading ability. One of the major findings from the studies was that the amount of musical training measured in year one was significantly correlated with the amount of improvement in reading fluency demonstrated in children over a three-year period. There has been also a very interesting incidental finding of the research: in the sample a correlation between exposure to the visual arts and improvements in math calculation was found.[14]

Also emotions influence many cognitive aspects such as attention, memory, perception and information processing. These considerations lead us to a final example which underlines the link between art expression and brain functions: the vast field of art therapy. The latter focuses predominantly on integrated visual and somatosensory information processing, i.e. on how images and their expression reflect emotional experiences and how the emotional experiences affect thoughts and behavior.

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[12] Michael Posner, Mary K. Rothbart, Bard E. Sheese and Jessica Kieras, *How arts training influences cognition*, in *Learning, arts and the brain – The Dana Consortium Report on Arts and Cognition*, p. 1-10 (2008).
[13] Joaquin M. Fuster, *Cortex and mind: Unifying cognition*, Oxford University Press, p. 85 (2003).
[14] Brian Wandell, Robert F. Dougherty, Michel Ben-Sachar, Gayle K. Deutsch and Jessica Tsang, *Training in the arts, reading and brain imaging*, in *Learning, arts and the brain – The Dana Consortium Report on Arts and Cognition*, p. 51-61 (2008).

Lusebrink[15] describes the main areas of interest when considering art therapy in respect to basic brain functions and structures. First, most of the perceptual stimuli are processed in parallel and unconsciously; part of the process is guided by cognition through selective attention in a top down manner. Second, brain structures provide alternate paths for accessing and processing visual and motor information and memories. Art therapy has the possibility to use these alternate paths and activate them through the use of art tools. Third, art therapy also offers the possibility to emphasize selectively different aspects of visual information processing. Forth, art therapy offers the possibility to deal with basic sensory building blocks in the processing of information and emotions. The most elementary expressive forms may reflect the underlying brain structures.

IV. ***CONCLUSION***

This short essay described which part of the brain structures are involved in photography (here considered as a form of art), which pathways connect them and which physiological reactions are the basis for the transformation of an external stimulus into an action potential. Moreover it was highlighted how the "concert" of firing neurons occurs through both parallel connections and sequenced associations between various parts of the brain. The final outcome is a push on the button of a camera, which is able to fix the one moment and thus provide us with some objective and subjective knowledge about the reality surrounding us. In that sense a parallel between the function of the art (in this case photography) and the function of the brain could be established: they both extract some knowledge about the continually changing reality.

We have seen that the process starts with an external stimulus which is further processed along well-defined pathways from the receptors to the other retinal neurons, from the ganglion cell to the lateral geniculate nucleus in the thalamus to end in the primary visual cortex. The whole path is characterized by two parallel pathways which convey different information basing on their different sensitivity to color and contrast. Once the information has reached the visual cortex or striate area we can again observe two parallel pathways of information going to the unimodal and multimodal association areas, in the extrastriate cortex, where the posterior parietal cortex (dorsal pathway) processes information about the *where* and the inferior temporal cortex (ventral pathway) about the *what* of objects.

[15] See footnote 7.

When looking at the integration of information from the sensory and motor systems we have seen that three important principles govern the functioning of the association areas, important for the visual brain. Firstly, information about form, color and motion is processed in a series of hubs along parallel pathways from peripheral receptors through primary sensory cortex and unimodal association areas (integration of information about different forms of one sensory modality) to the posterior multimodal association areas (integration of information about several sensory modalities). Secondly, information representing different modalities converges upon areas of the cortex that integrate them, namely the multimodal association areas. Thirdly, the posterior association areas that process sensory information are highly interconnected with the frontal association areas responsible for planning motor action. In sum, multimodal association areas transform sensory information into planned movement and further through the premotor and primary motor cortex into implementation of motor action.

The motor information goes through the corticospinal tract and is modulated by sensory information and other motor regions providing a mix of inhibitory and excitatory signals. This includes a continuous flow of tactile, visual and proprioceptive information needed to make voluntary movement both accurate and properly sequenced. In addition, the output of the motor cortex is impacted also by other motor regions of the brain, including the cerebellum and the basal ganglia, that provide the information for smoothly executed movements.

We have also seen that information regarding both memories and emotions can be integrated in the multimodal motor association cortex. The recall of perceptual memories involves ventral and dorsal streams for the two types of visual information. Executive memory is stored in the frontal cortex. The prefrontal cortex performs the integrative functions of working memory, attention and inhibition. Motor memories of concrete and stereotypical sequences of actions are stored in the basal ganglia. Long-term or declarative memories involve two brain areas: the right hippocampus and the right prefrontal cortex. Emotions involve patterns of autonomic activity and hormonal and cortical responses. The integration of these different inputs takes place in the amygdala, whose connections to the neocortex are either direct or indirect through the thalamus to the orbito-frontal and the prefrontal cortex. Moreover, selective attention has been highlighted as a key factor in enhancing the strength of a response to an external visual stimulus.

In the final section of this paper we have seen some examples on how the interaction between art and brain can also be reversed, seeing art not only as a tool for providing an output of brain activity, but also be itself an activity able to shape neuronal patterns and enhance certain cognitive functions among which reading ability and math.

In conclusion, this essay has tried to describe how the process of seeing and then capturing a specific moment into a picture – an action which lasts a fraction of a second – involves the elaboration of various sensory stimuli, the visual being the most important, and its integration with a number of other stored data concerning memories and emotions, as well as motor action.