Perception Is Movement, Movement Is Perception

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Abstract

In this paper, the function of receptive and processing neurons is distinguished from that of neuronal circuits. The former, which are inside the circuits, collect and elaborate sensorial information to build "objects" which are spatially and temporally well-structured and vary in intensity. These objects are the modal components of sensory systems: hot/cold, smooth/rough, green, table, sound, etc. motionless or in motion. On the other hand, perceptual and motor neuronal circuits have the function of *positioning* the "objects" in *space* and *time* in an orderly way. This process of positioning, being regularly repeated in space and/or time, determines *groupings* and *fillings* which give rise to "blocks", that is, significant constructs of objects grouped in space and/or time and then stored. These blocks are divided into *maps*, stored in the posterior areas of the cerebral cortex, and *dynamisms*, stored in the anterior areas of the cerebral cortex. One of the functions of dynamisms is *selection*. Positioning is fulfilled through four distinct processes: *anticipation*, *programming*, *execution* and *verification*. Maps are divided into anticipation (or modal) maps and programming (or spatio-temporal) maps. Damage to modal maps generates impairments in the identification of stimuli, associative agnosia, ideational apraxia, Wernicke's aphasia; damage to spatiotemporal maps generates impairments in the perception of stimuli, apperceptive agnosia, ideomotor apraxia and parietal disorders related to language. Anticipation consists of two functions: 1) the *unconscious pre-activation* of stored data generated by conscious perception; 2) the *selection* of one of the pre-activated data. Pre-activation pertains to "maps" and "objects". Selection can be performed on maps (movement and perception) or objects (mental representation). The memory of a circuit where maps are selected is called "procedural memory". After the initial positioning, the same process (*meta-positioning*) can be repeated. This allows linguistic correlations, spatial and temporal relations, and classifications to be made.

Keywords

Perceptual-motor circuit, positioning, focusing, perception, anticipation, programming, execution, verification, pre-activation, selection, block, modal maps, spatiotemporal maps, procedural memory, meta-positioning, surface structure, deep structure, relation.

Introduction

When dealing with brain functions, we can use two distinct approaches. The first is to analyze the function of any single neuron or population of neurons within the various neuronal circuits. The second is a more general approach and involves analyzing the functions performed by neuronal circuits.

The function of receptive and processing neurons belonging to neuronal circuits is to build "objects" which are spatially and temporally well-structured and vary in intensity. These objects are the modal components of sensory systems: hot/cold, smooth/rough, green, table, sound, etc. motionless or in motion.

The primary function of perceptual-motor circuits is to *position these objects in space and time in an orderly way*. This act of positioning is a twofold process of *grouping* and *filling*. The results of this twofold process are "blocks", that is, "unitary, significant constructs".

1) Elaboration processes

The first function is well documented by several studies which, since the early 60's of last century, have shown how information coming from sensory receptors, after being spatially organized and divided into different pathways, is elaborated both in its course towards the primary areas and within them. Only some of the several elaboration processes will be mentioned here. We can start our survey with the subcortical function of relay nuclei.

a) Relay nuclei

Neurons receiving information directly from the outside are called "sensory receptors". Every sensory receptor has its own "receptive field", that is, the receptive area innervated by the terminals of the sensory receptors. Each receptor responds only to, and transduces, stimulation within its receptive field. Neurons acting as receptors converge on second-order neurons which, in turn, come into contact with third-order neurons; once again, the latter come into contact with higher-ranking neurons and so on.

At a subcortical level, that is, before signals reach the primary perceptive areas in the cortex, information is transmitted from low-ranking to higher-ranking neurons of "relay nuclei". The receptive field of the neurons of relay nuclei is composed of the afferences that come from the "sensory receptors" either directly or indirectly. However, receptive fields of higher-ranking neurons are larger and more complex than those acting as receptors.

While the receptive fields of sensory receptors are simple and only excitatory, the receptive fields of the neurons of relay nuclei usually have both excitatory and inhibitory zones. The addition of an inhibitory zone to the receptive field is an important mechanism that increases the contrast between stimuli and allows sensory systems to enhance their power of "spatial resolution" (Martin, 1991).

b) The spatial position of sound sources

As stated, the processing of sensory information also takes place at a cortical level. In the primary auditory cortex, the brain uses the different times at which sounds reach both ears to determine the spatial position of a sound source. Frequency and time are coded by parallel pathways. In the primary auditory cortex, frequency and time are mapped along axes placed orthogonally in order to establish the temporal sequence of isofrequent auditory stimuli. These time differences allow the position of a sound source to be identified (Kelly, 1991a).

c) The shape of objects

A further example of information processing at the primary cortex level is provided by Hubel and Wiesel (1968), whose studies focused on the "primary visual cortex". These authors succeeded in explaining how we perceive the "shape of objects". In the primary visual cortex, neuronal columns – called "orientation columns" - perceive variously oriented segments. They are arranged to allow the primary visual cortex to form a cortical representation for any orientation axis as well as for any retinal localization. Furthermore, these columns are organized in hyper-columns. Therefore, the shapes of objects found inside the visual field that we are focusing on, activate at the neuronal level the set of columns codifying those very shapes.

The orientation columns are reached by stimuli coming from neurons which have a central/peripheral organization. They are cells with a concentric receptive field and can be divided into two groups: "on-center" and "off-center" cells. By collecting information from this typology of neurons, the cells of orientation columns can synthesize the various segments and determine the shape of objects (Mason & Kandel, 1991).

d) Visual perception of movement

Another neuronal mechanism of the primary visual area was used to explain the visual perception of movement. In this case, the mechanism is based on a spatio-temporal dimension. Some cells of the primary visual cortex record rapid variations of luminous intensity over time. As a result of the retinotopic organization of these cells, populations of neurons are activated when there are rapid changes in luminosity for any given point of the visual space. This spatio-temporal organization lies at the basis of movement perception (Kelly, 1991b).

Therefore, we can say that at a mental level, an object which appears well-structured in front of us, is the result of a complex constructive process. This process starts with sensory receptors and ends in the primary perceptive areas. Everything we feel, hear, see, etc. is constructed by our mind in a split second and it is this rapidity that gives us the illusion of a well-shaped “reality” around us. Every “object” is organized in relation to space, duration and intensity.

2) Perceptual-motor circuits

a) The primary function of a perceptual-motor circuit

There are not just motor circuits, as there are not just perceptual circuits. Every motor act includes perceptive components and every perceptive act includes motor components. In fact, movement definitely includes three components: motor programming, muscle contraction/relaxation, and somato-sensitive and positional sensations sent by skin receptors and neuromuscular spindles.

Motor programming plans the movement to be performed by the primary motor cortex by activating motoneurons. These innervate muscles which, in turn, contract and relax according to the inputs. The neuromuscular spindles and peripheral receptors of skin send information on the position of body areas and their presence to the primary somato-sensitive cortex. This information is sent to the areas responsible for programming (pre-motor cortex).

However, movement programming is not based on information coming from peripheral organs, but on a hypothesis of *their position*. Consider, for example, the motor act of walking. When children learn to walk, they try to toddle keeping the erect position and balancing their bodies. We can state that children’s walking consists in *positioning* their lower limbs into space following a temporal order, that is, one after the other.

This positional awareness of lower limbs accompanying movements at every instant is of a sensory type. However, if motor programming was guided by the positional awareness determined by the signals coming from the peripheral receptors of lower limbs, then the movements would be slow. On the contrary, it is the hypothesis of this awareness that guides motor programming. The information coming *after* muscle contraction/relaxation simply *verifies* the validity of this positional hypothesis. The latter consists in two components: the "awareness of lower limbs", that is, "what are" lower limbs, and the "awareness of their position", that is, "where" they will be positioned. This is a kind of implicit awareness, which becomes explicit only during the movement thanks to the modal and spatio-temporal information coming from the sensory receptors. The process that *includes* the modal hypothesis ("What") is called "anticipation", the process that *includes* the positional hypothesis is called "programming".

The main difficulty children experience is not connected to motor programming but to the integration of *anticipation* and *programming*. Legs, feet, and the hardness/softness of the floor are built at every moment by processing neurons; on the other hand, the task of perceptual-motor circuits is to *position* them in space in a temporal order.

b) The specific function of circuits

The major aim of this essay is to show that the "focusing" process is a "movement". This is quite obvious with "visual focusing" and "tactile focusing", the former occurring through the ocular-motor circuit, the latter through the body's movement. The motor act at the basis of auditory or olfactory focusing is less obvious. However, it is known that animals that use their sense of smell to identify things around them move their heads and inhale air with precise voluntary movements.

"Auditory perception" is also accompanied with head movements that facilitate the focusing of attention on sound. If we simply hear the word "hello", we have to "focus" our attention on it in order to "perceive" it. Since the focusing process is a movement, it is tantamount to a positioning act. In this case, the positioning takes place along the temporal axis. The positioning is performed by the perceptual-motor circuit of the sense of hearing; the sound is built in real-time by sensory receptors and processing neurons. Also in this case, we have modal anticipation, motor programming, execution and verification.

The architecture underlying the act of walking is similar to that of hearing. The only difference lies in the typology of movement. When we are walking, the movement is performed by the primary motor cortex through motoneurons that innervate the muscles; on the other hand, when we are hearing, the movement consists of a set of "focusing" acts in a time-ordered sequence (Fig. 1).

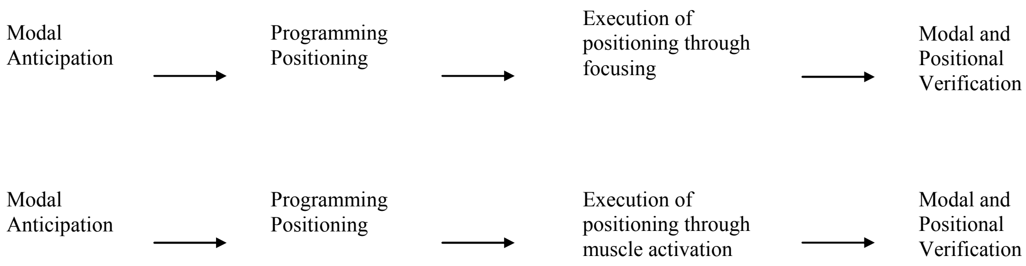


Figure 1. Architecture of hearing process (above) and walking process (below)

The same is true for visual perception through the ocular-motor circuit. If we are perceiving two pictures on a wall, it is ocular movement to "position" both objects in the space, objects which are built by sensory receptors and processing neurons.

c) Motor act and perception

It is widely believed that motor acts differ from perceptions, but after a more careful consideration we can see that this is not the case. When we move our arm, processing neurons build the object (arm) that has been positioned by the motor circuit in real-time. This process is the result of the information coming from the sensory receptors and neuromuscular spindles. Without this information, the circuit would not have anything to position. The processing neurons, in fact, are located inside the motor circuit and the somato-sensitive building of the arm takes place in parallel with the motor act. In confirmation of this, we can see how damage to the primary somato-sensitive cortex (where the building of the object is completed) hampers the correct execution of movements (Kandel & Jessel, 1991).

The same occurs with perception. Processing neurons build the object and the motor circuit positions it. Even in perception, the processing neurons are inside the motor circuit and without these the circuit is hindered because it would not have anything to position (Kandel & Jessel, 1991).

d) The organization of the primary visual cortex

In every modal context, the focusing process can refer to “presentiated things” - a term introduced by Ceccato (1964) and then used by Vaccarino (1988) - and “objects”. Examples of presentiated things are hot/cold, smooth/rough, green, etc. For presentiated things, with our sense of touch we can focus on “hard/soft”, smooth/rough”, etc; with our sense of hearing we can focus on “low/high”; with our sense of sight we can focus on “color”, “shape”, “motion/stasis, “size”, “light/dark”, “transparent/opaque”. For objects, with our sense of sight we can focus on a “leaf”, a “table”, etc; with our sense of hearing we can focus on “words”, “melodies”, “sounds”, etc.; with our sense of touch we can focus on “apple”, “mouse”.

This implies that the process of building objects and presentiated things which can be focused on is carried out in several areas of the primary perceptive cortexes. We call these areas: *primary focusing areas*.

Let us consider the primary visual cortex. As we have already noted, by using our sense of sight we can focus on “objects” (and scenes), such as, a leaf, or we can focus on any of their characteristics (presentiated things): color, shape, opacity, motion (or stasis), size, light/dark. When we focus on a leaf, its characteristics are seen but not perceived in detail. To focus on its color we need to “move” our eyes on the color. The same applies for the perception of its shape or size. This is made possible by the organization of the primary visual cortex. Information coming from the sensory receptors that code the various characteristics of the stimuli, travels towards the primary visual cortex along parallel pathways (Martin, 1991).

Every characteristic is independent and is processed separately. Being arranged in different layers of the same column, neurons V1area coding the various characteristics converge in the (Mason & Kandel, 1991). Therefore, V1 is probably the “primary focusing” area for scenes and objects and because of this area, the perceptive ocular-motor circuit can focus on scenes and objects in their integrity, including all of the visual characteristics. The selected object has a shape, color, size, opacity, luminosity and state (still or in motion). The selected object is *perceived*, while its characteristics are *seen*, but not *perceived* (see below: “Binocular Rivalry”). From the V1 area, the neurons that process the object’s characteristics, project and end their elaboration process in the various areas of the primary visual cortex. For example, colors are coded in the V4 area, the various types of movement are coded in the MT and MST areas (the Middle Temporal area -MT- and Medial Superior Temporal area -MST- are not considered as belonging to the primary visual cortex, although their functions are similar to those of the V4 and V1 areas). The V4 area is, therefore the primary focusing area for colors (*perceived*), while MT and MST are the primary focusing areas for movements (*perceived*). The primary focusing areas for shape, size, "transparent/opaque", "light/dark", etc. are located in the V2, V3, V4 areas etc.

The organization of any other primary perceptive cortex is similar to that of the primary visual cortex. Each characteristic of the stimulus is processed separately but in parallel to the other characteristics. In primary cortexes, there is a primary focusing areas for each focusing act performed by perceptual/motor circuits.

e) Binocular rivalry and conscious perception

Binocular rivalry is a phenomenon by means of which, under specific circumstances, an object *seen* with one eye is different from the object that is *seen* with the other eye. In this case, when one eye dominates over the other, an alternation in the *conscious perception* of two objects can be noted. When the left eye is dominant, the subject *perceives* what the left eye *sees*, but *does not perceive* what is *seen* by the right eye. On the contrary, when the right eye is dominant, what *is seen* through the right eye reaches consciousness and its object *is perceived*.

Ingenious studies on monkeys have focused on this phenomenon and researchers have reported on the response of stimulus-sensitive neurons under two conditions: 1) when the stimulus is *seen* but not *perceived*; 2) when the stimulus is *perceived*. The stimulus is *seen* when stimulus-sensitive neurons on the primary visual area fire. The stimulus is also *perceived* when the monkey reacts to it. The animal's reaction implies a conscious perception. The results were surprising. By recording the activity of the MT/V5 visual area, where cells tend to be responsible for movement, Leopold and Logothesis (1996) found that only 43% of cells in this area changed their level of activity when passing from one condition (perceived stimulus) to the other (the stimulus is seen but not perceived). In other words, only 43% of stimulus-sensitive neurons in this area is related to conscious perception. A higher percentage is responsive to the stimuli to which it is sensitive irrespective of whether they reach consciousness, that is, whether they are perceived, or not. Similar findings have been reported in the V4 area. In this area, the percentage of cells involved in conscious perception was similar to that found in the MT/V5 area: about 40 percent. In V1 and V2 less than 10% was sensitive to a more effective stimulus. On the contrary, in the inferior temporal cortex, the response of most neurons, about 90%, is related to perception, as demonstrated by Leopold et al. (1996).

This data should be combined with the results obtained by Lumer et al. (1998) from London University College who investigated visual signals that reach consciousness, i.e., that are perceived. Using fMRI, they showed that the temporal lobe of humans is activated during the conscious experience of a stimulus, as in monkeys, while other regions, such as parietal and prefrontal cortical areas, are activated only when the subject refers that the stimulus is changing.

f) Architecture of perceptual-motor circuits

If these observations are extended to the other sensory modes (hearing, touch, taste, smell), we can assert that the function of modal anticipation and motor programming can take place thanks to a filtering of the information coming from primary areas. The mind "determines" "what" has to be perceived among several modal options. Based on this "determination", the programming of the positioning of a given object is activated.

As we will see later, this selection acts on data that does not come directly from sensory receptors, but from stored information that is automatically activated after a conscious perception. The perceptual motor circuit is also a circuit that selects pieces of information. This selection, which is part of the anticipation mechanism, is carried out on mnestic components that are activated after a conscious perception (Fig. 2).

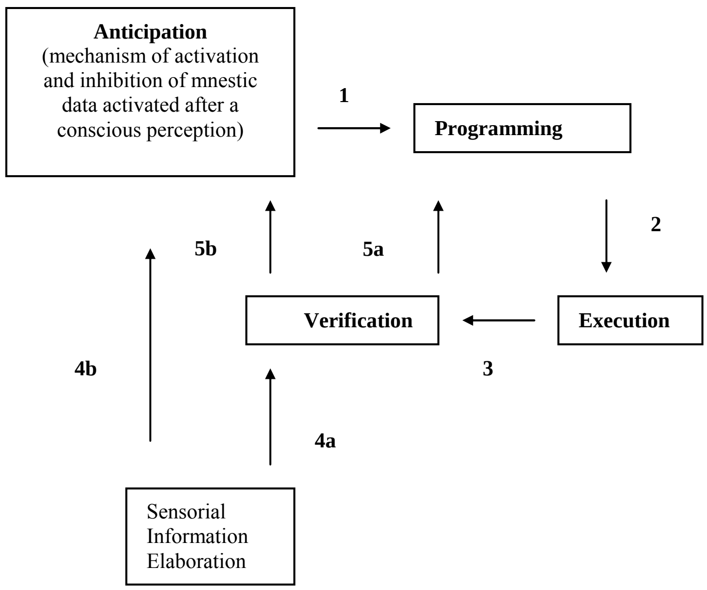


Figure 2. Structure of Perceptual Motor Circuit

g) Modal maps, spatio-temporal maps and dynamisms

We have already said that the primary function of perceptual-motor circuits is to focus on various objects and that this focusing consists in a "positioning" in space and/or time. As we will see later, the positioning of objects takes the form of a grouping (or filling) into meaningful "blocks". Blocks are built by circuits. The memory of blocks is therefore a circuit memory.

Modal and *spatio-temporal maps* of these blocks, which are built in space and/or time, are stored in posterior associative areas. These maps (made up of populations of neurons) are linked to primary focusing areas, as well as to prefrontal and premotor areas. Anterior areas carry out the functions of anticipation and programming using modal (anticipation) and spatio-temporal (programming) maps.

Anticipation and programming are processes. *Selection* is a dynamism of anticipation. Some other dynamisms of anticipation are *retrieval* and *presence keeping*. Most probably, there are some other dynamisms in anterior areas as well.

As far as programming dynamisms are concerned, they are functional to movement and focusing. What is selected or retrieved is subsequently programmed for the motor act or fro focalization. Programming itself contributes to *presence keeping*.

3) The object

a) The object and its characteristics

The "object" that establishes the context is the first to be positioned. At a visual level, this is usually a scene, such as a room. In order to make things clearer, let's start from the position of a leaf on a branch. If we then focus on the green color after focusing on the leaf, we position it in a spatial order with respect to the leaf, and we will do the same when we focus on the shape, on light/dark, etc. Imagine taking the color from the primary focusing area and positioning it in a spatial orderly way with respect to the leaf (seen as a whole); and then imagine repeating the same procedure with shape, opacity, and state (of stillness). This set of activities gives rise to a "block" containing the object and its characteristics. It is a "meaningful block" since its characteristics are an integral part of the object.

The result of this positioning is that we are aware that shape, color, opacity and state are characteristics of the leaf (seen as a whole). In fact, the spaces seem to overlap. This series of focusing acts generates two maps – one is a modal map of anticipation, the other a spatio-temporal map of programming – which are related to the leaf and its characteristics.

Modal maps pertain to the *ventral pathway* ("what") and spatio-temporal maps to the *dorsal pathway* ("where") (Livingston and Hubel, 1988). The anticipation, modal map is thus located in the inferior-temporal cortex, that is, the area where information of the ventral pathway, coming from the primary visual cortex, is projected; the spatio-temporal programming map is stored in the parietal cortex, that is, the area where information of the dorsal pathway, coming from primary visual area, is projected (Ungerleider and Mishkin, 1982).

When we perceive the leaf as a whole, the sensory information coming from V1, once it reaches the inferior temporal cortex, activates a modal map linking the object "leaf" to the presentiated things "green", shape, opacity, etc. This is the reason why the perception of the leaf as a whole leads to activation of the other "presentiated things" as well: it is as if we also perceive and identify the characteristics of the leaf at a single glance. We are able to use green to color a black-and-white drawing of a leaf exactly because the modal map of the object "leaf" and the presentiated thing "green" is stored in the inferior temporal cortex (Luzzatti and Davidoff, 1994).

When we perceive the leaf as a whole, sensory information coming from the primary visual cortex reaches the parietal cortex. This information activates the spatio-temporal map linking the space of the leaf to the space of color, shape, etc. In a split second, the spatial and temporal links between the object, its characteristics and its context are automatically activated.

Furthermore, the programming map is the spatio-temporal map that allows for the *execution* of positionings in space. It supports the executive memory of the primary motor cortex. Without the programming map, object positioning couldn't be carried out correctly.

b) The object and its components

"Objects" can be divided into two categories: "Simple Objects" and "Complex Objects". "Simple Objects" include only characteristics. "Complex Objects" include other objects. Almost any object that we see is a "complex object"; i.e. an object that includes other objects. A leaf is composed not only by the "object" leaf and its characteristics (e.g., color, shape, etc.), but also by a stem, veins, and so on. The stem and veins are *components* of the "complex object" leaf.

The components of a visual object are also positioned in space through focusing. This occurs in the same way as characteristics are positioned.

The spatio-temporal memory plays a major role in complex objects. In fact, for simple objects the spaces of the object and its characteristics often overlap. For complex objects, on the other hand, the various objects forming its components occupy different spaces. Take the image of a leaf. If we want to draw its stem we need to have memorized its position on the body of the leaf; and the same is true for veins. The automatic activation of spatio-temporal links between the complex object and its components allows us to "identify" their reciprocal "position" instantly.

c) Maps and objects

"Anticipation" maps are defined as being maps that "anticipate" the modal components (the "what" pathway) that will arrive from primary focusing areas an instant "later". These maps are more *general* than modal components.

Let us consider a face. The inferior temporal cortex stores the maps of faces in general, seen from different positions: front view, profile or from various angles (Desimone, 1991). The memory of a specific face, for example that of my friend John, is an association between anticipation maps and relative constructs in the primary focusing area. It is exactly in this area, in fact, that the realization of a specific object is achieved. The same can be said for "shape", "color", etc.

Programming depends on anticipation. Anticipation can be considered as the ultimate goal of motor programming. You anticipate the positioned face (in general) and program the focusing required for this anticipated perception.

Just like the modal anticipation map, the spatio-temporal programming map is *general* with respect to the specific spatio-temporal "elaborations" coming from V1. It is this very difference between general (modal and spatio-temporal) maps and "constructs" in primary focusing areas that determines the type of identification.

Identification can be general or individual. In looking at a face we can identify a "person" (in general) or John (individual). The different identification may depend on how many components and/or characteristics are associated to the maps that are automatically activated. When we meet a "person" and perceive her face, the maps that are automatically activated (such as that of her eyes) are not associated to any specific characteristics (such as the shape of the eyes, etc.), but simply provide general information. After repeated observations of the person, a specific component and/or presentiated thing will be associated to each map so that, when we will meet the person again, they will be activated along with their map. In this case, the identification is individual.

The same happens with spatio-temporal "positions". When you look at a person's face, spatio-temporal maps are automatically activated in relation to the position of her eyes, mouth, etc. These maps are not associated to any spatio-temporal elaboration in the primary visual area. Positional identification is general; it does not refer to a specific face. After repeated observations, spatio-temporal maps are associated to specific positions elaborated in the primary area, so that when we will meet that person again, the perception of her face activates not only maps, but also constructs of the primary area. In this case, the *positions* of the components of that specific face will be identified.

Spatio-temporal maps allow us to identify "objects" we have already memorized based on their position. This is the case, for example, of organs and parts of the human body. Noteworthy here is autotopoagnosia, which occurs after damage to the left parietal lobe (Denes, 1996).

4) Grouping and filling

a) Grouping

Let's imagine we are looking at a light with changing colors such as a traffic light:

green → yellow → red

During the act of perception, we position the three colored lights one by one in time:

anticipation green → programming green → focusing green → verification green; anticipation yellow → programming yellow → focusing yellow → verification yellow; anticipation red → programming red → focusing red → verification red.

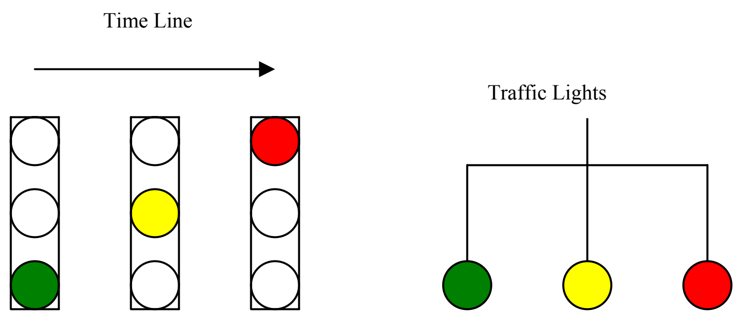
Some instants later, however, the sequence is memorized. We obtain:

anticipation green, yellow, red → programming green, yellow, red → focusing green, yellow, red → verification green, yellow, red.

As we can see from the example above, in order to memorize the temporal sequence it is not sufficient to position the objects in time. We need to group them, generating a "block". Grouping is accomplished through anticipation, programming and focusing. To group the three colors, we need to anticipate and program a kind of focusing activity by means of which we pay constant attention to the light source for as long as the green, yellow and red follow one another. We therefore anticipate the alternation of the three colors, program it, focus on it and verify it.

The memory of blocks is a circuital memory. Each component of the circuit takes part in the block-building process with its functions and does its share of the memorizing. Modal maps are unitary maps that memorize: the lighting up of the green, the lighting up of the yellow, the lighting up of the red, and the lighting up of the sequence green-yellow-red. The anticipation dynamism (prefrontal cortex) memorizes the retrieval and selection (see below) among the various pre-activated options in modal maps. The spatio-temporal maps memorize spatio-temporal relations between single units in modal maps (lighting up of green, yellow and red). These maps allow for the *temporal* division of modal units. Without them, the *unitary block* of color lighting could not consist of a *temporal sequence* of *three* colors. Thanks to temporal maps, programming dynamism divides the focusing process into three temporal sequences.

When grouping, our mind does not act randomly but on the basis of meanings. "Objects" are grouped when a meaningful "block" is formed. Let's go back to the example of the three-color traffic light. In our daily life, grouping the three colors and connecting them to a lamp seen in a shop window would make no sense. However, it could be useful to group the three changing colors of a traffic light. This "block" allows us to anticipate the green, yellow or red and to act accordingly. In this case, the "block" is meaningful and is called "traffic lights" (Fig. 3).



Figur3 3.The grouping of traffic lights over the time line.

The memorization of groupings along the temporal axis occurs frequently. Examples are the days of the week, seasons or months of the year (Fig. 4).

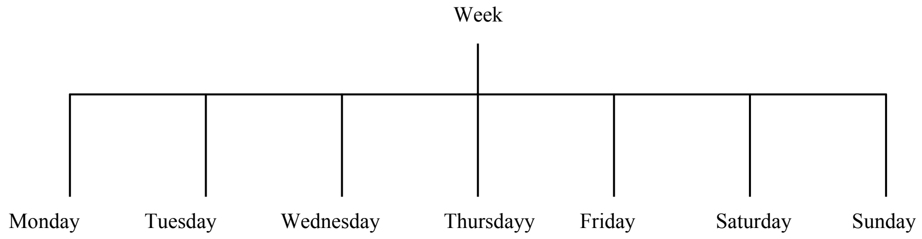


Figure 4. The groupings of the days of the week over the time line.

b) Filling

As far as the visual field is concerned, a scene can be focused on with a single gaze. The positioning of a scene is followed by the positioning of any single object which is perceived in greater detail. This process can be called "filling". The focusing of a scene involves several objects (seen, but not perceived); subsequent focusing acts position the objects within the scene, filling it.

The grouping and filling processes are simply two different ways of positioning the objects constructed by processing neurons.

When we look at an object with its characteristics and components, our mind uses both the filling and grouping processes to have a more detailed description of the object.

c) Groups and subgroups

Let's return to the example of traffic lights. After positioning the three colors, we can group the green and yellow with a single long gaze, which is followed by the perception of red. In this case, two blocks are formed, the first is the "green-yellow" color sequence; the second is the "green-yellow" block and the "red" color sequence [(green – yellow) – red]. One block (green – yellow) is a *subgroup* of the other block [(green – yellow) – red].

The positioning of "objects" that are components of a "complex object" often occurs by subgroups. Consider the case of faces. In order to memorize a face, we often use subgroups such as:

the area of the eyes (including eyelashes, eyelids, iris and pupil) (Perret et al., 1987) and that of the mouth (including the mouth itself, teeth, nose, chin, etc.).

d) Positioning

Positioning processes vary from one individual to another and some are more efficient at memorizing than others. Some people acquire such an effective technique that they are able to memorize a face they have seen for short time; others are not able to identify people they have talked with for hours. The former are said to have a photographic memory.

Once a face has been memorized along with its characteristics and components, it is possible to pass (position) from one characteristic to another, and from one component to another. We can thus picture the face of a person who is dear to us and then move on to his/her eyes, lips, etc. The number of these transitions (positionings) may be considerable and depends on how many times we have carried out the same positioning operation in our life.

Grouping and filling may also refer to actions. Before learning to drive a car, the three acts of pressing on the clutch, moving the gear stick and releasing the clutch are anticipated, programmed, executed and verified one by one; once we have acquired experience the three acts are grouped into a single action. The anticipation, programming, execution and verification of these three acts are carried out in a single transition. They form a meaningful block: “changing gear”.

5) Agnosia and apraxia

a) Apperceptive and associative agnosia

As discussed, the functions of the perceptual-motor circuit account for the difference between perception and identification rather well. Sims (1997) distinguishes, for every sensory field, disorders in the perception of stimuli from disorders in the identification of stimuli. In my opinion, disorders of stimulus perception are related to spatio-temporal maps and are caused by parietal cortex damage; on the other hand, disorders of stimulus identification are related to modal maps and occur after damage to the temporal cortex (sight and hearing).

The first neuropsychologists had already speculated on the existence of these two levels. For instance, Lissauer (1890) distinguished the level at which sensory features of stimuli are analyzed in order to obtain a structured perception, from the level of stimulus identification, which is achieved by activating the network of knowledge of the physical, functional and categorical features of stimuli (De Renzi, 1996).

The impairment of the former level produces *apperceptive agnosia*, while the impairment of the latter produces *associative agnosia*. According to our hypothesis, apperceptive agnosia is caused by damage to spatio-temporal maps; on the other hand, associative agnosia is produced by the impairment of modal maps.

The failure to identify faces, for example, can occur either when modal maps or spatio-temporal maps are impaired. Noteworthy here is that prosopagnosia, also known as face-blindness, can refer to familiar faces (even one's own face) or to unfamiliar faces. Prosopagnosic subjects whose temporal cortex is damaged cannot identify familiar faces (associative agnosia); prosopagnosic subjects with parietal lobe lesion (apperceptive agnosia) cannot recognize unfamiliar faces (obviously when these are seen on two or more occasions) (Van Lancker and Carter, 1982). This data is easily explained if we consider that the perception of a familiar face automatically activates modal maps and the associated objects. An immediate identification is thus performed.

If we look at a face and are not able to recognize it immediately with our modal maps, we then start a series of ocular movements to position several objects (eyes, nose, forehead, etc.); consequently, spatio-temporal maps allow a face to be identified based on the position of its components.

It is because of modal maps that we recognize a face based on a detail.

In general, we can say that, when anticipation memory is of no support, we can remember an object, a scene, etc. by repositioning objects, characteristics and elements by means of ocular movements.

b) Ideational apraxia and ideomotor apraxia

We have said that the architecture of the circuits devoted to perception (focal movements) is similar to that of circuits devoted to motoneuron-based movement. This is the reason why perception and movement pathologies are very similar. One example is ideational apraxia, which was first described by Pick (1902). His patients made mistakes using daily objects even though they were able to identify them. For example, they would use a pair of scissors like a spoon by taking them to their mouths; they were not able to light a candle because they proceeded by trial and error using an unlit match around the candlestick (De Renzi and Faglioni, 1996).

Another form of apraxia is ideomotor apraxia. Generally, subjects suffering from ideomotor apraxia cannot perform one or more gestures requested by the researcher.

De Renzi and Faglioni distinguish two forms of apraxia: subjects suffering from ideomotor apraxia know what they must do to perform the task they have been assigned, but fail when they must transform the ideational plan into a set of suitable innervations, that is, they do not know *how* to do it; on the contrary, subjects suffering from ideational apraxia are not able to remember the gesture they need to make; they omit or invert the order of actions, use movements for an object that should be used for another object: that is, they do not know *what* to do. Let's consider the action of lighting a candle, which consists in a sequence of acts in a temporal order: lighting a match by producing friction against the box → lighting the candle. In order to light the candle, two gestures (each of which consists of a set of motor acts such as: taking the box, opening it, picking up a match, taking the lit match to the candle, etc.) need to be *anticipated* and then *programmed in a temporal order sequence*.

Modal maps, which allow us to identify a gesture or a set of gestures, are used in anticipation. They are impaired in ideational apraxia. Spatio-temporal maps, which allow us to identify spaces and the times of gestures, are used in programming. They are impaired in ideomotor apraxia. Using De Renzi and Faglioni's definition, we can say that ideational apraxia affects the anticipation phase and the subject does not know *what* to do; ideomotor apraxia affects the programming phase and the subject does not know *how* to do it. Ideational apraxia corresponds to associative agnosia, while ideomotor apraxia corresponds to apperceptive agnosia.

6) Anticipation process

a) Pre-activation

Let's suppose we have memorized John's face. It is a block made up of several components, such as the eyes, forehead, nose, etc. Let's also suppose now that John is present. After perceiving his face, anticipation *modal maps* in the inferior temporal cortex for the areas of eyes, nose, etc. as well as programming *spatio-temporal maps* in the parietal cortex are activated. These (modal and spatio-temporal) maps are functional to anticipation and programming, respectively. Modal anticipation is followed by the programming and execution of positioning of the object that the sensory receptors and processing neurons are going to build. In fact, anticipation, programming and execution of positioning occur a split second before sensory activity starts.

Since pre-activation involves various modal and spatio-temporal maps, I believe that there must be an activation/inhibition mechanism in anticipation that, among various pre-activations, selects the modal map of the object to be positioned (Fig. 5).

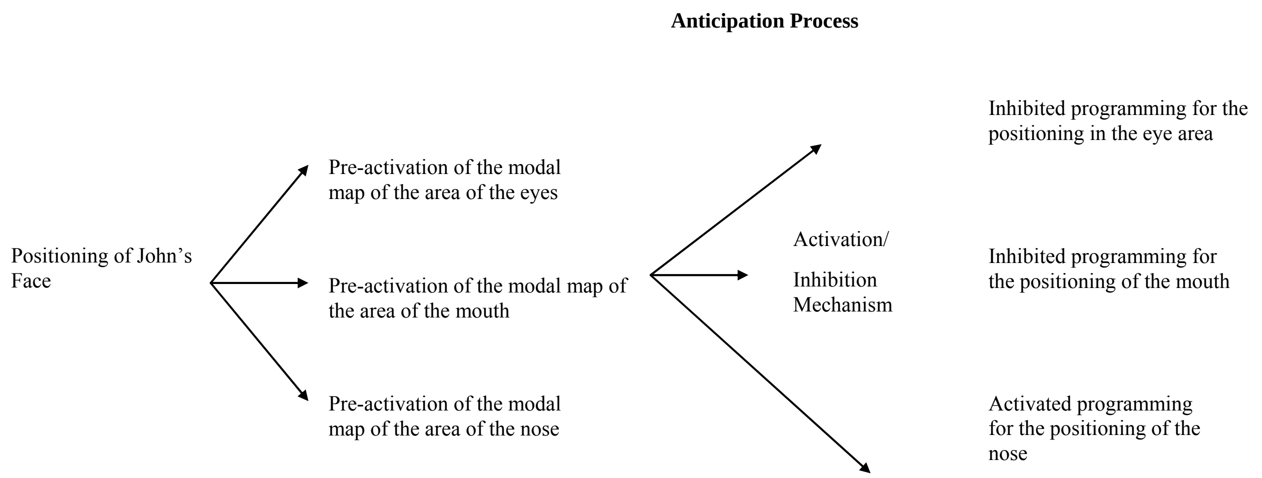


Figure 5. Pre-activation and Activation/Inhibition Mechanism within the Anticipation Process

I think that this mechanism is part of anticipation because the latter comes before programming. After the prefrontal cortex, "has chosen" "what" is to be perceived by means of the activation/inhibition mechanism, the pre-motor cortex programs the specific movement (aimed at perception), by using one of the pre-activated spatio-temporal maps.

Let's consider the situation in which the perception of our friend John's face pre-activates the modal map of his eyes, iris and color. This means that, before perceiving the green color of John's eyes as well as their shape, they are pre-activated. Indeed, if we look at John's eyes and perceive their color is light brown, we wonder whether our friend was wearing contact lenses.

Let's consider now the situation in which the perception of unfamiliar faces activates the modal map of eyes, iris and color. Given that we do not know the shape and the color of a stranger's eyes, what modal components are activated along with maps? I think that here pre-activation involves shapes and colors that are common to a specific environment. If we are in Sicily, the colors that will be activated are dark brown, light brown, etc. (Fig. 6).

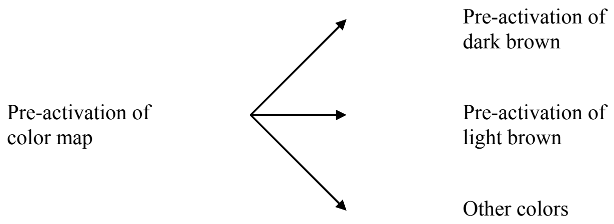


Figure 6. Pre-activation of the map of the iris and the modal component of the colors of iris

After positioning the "real" color (light brown) of the stranger's eyes, this color is associated to the map of the iris. When we meet the same person on another occasion, a pre-activation of the iris map will pre-activate the "light brown" color automatically.

b) Choice options

The activation/inhibition mechanism acting on modal pre-activations is in all accounts a choice mechanism that belongs specifically to the pre-frontal cortex (Robinson et al., 1998). Pre-activations are unconscious. The selection mechanism selects the one that will become conscious after the programming and execution, from among the unconscious pre-activations. In other words, pre-activations are various options on which selection is performed.

The various pre-activated options can be made conscious through the positioning carried out by either *mental representation* or *focalization*. The prefrontal cortex can act in two different ways:

1) It "decides" (through the activation/inhibition mechanism) to *look at* the color of the eyes (it selects the "*eye color* map" option, which is already pre-activated) and, based on this "decision", the programming and execution take place followed by perception.

2) It "decides" (through the activation/inhibition mechanism) to *mentally represent* the color "green" (it selects the "green" option, which is already pre-activated) and, based on this "decision", programming and execution take place (Fig. 7).

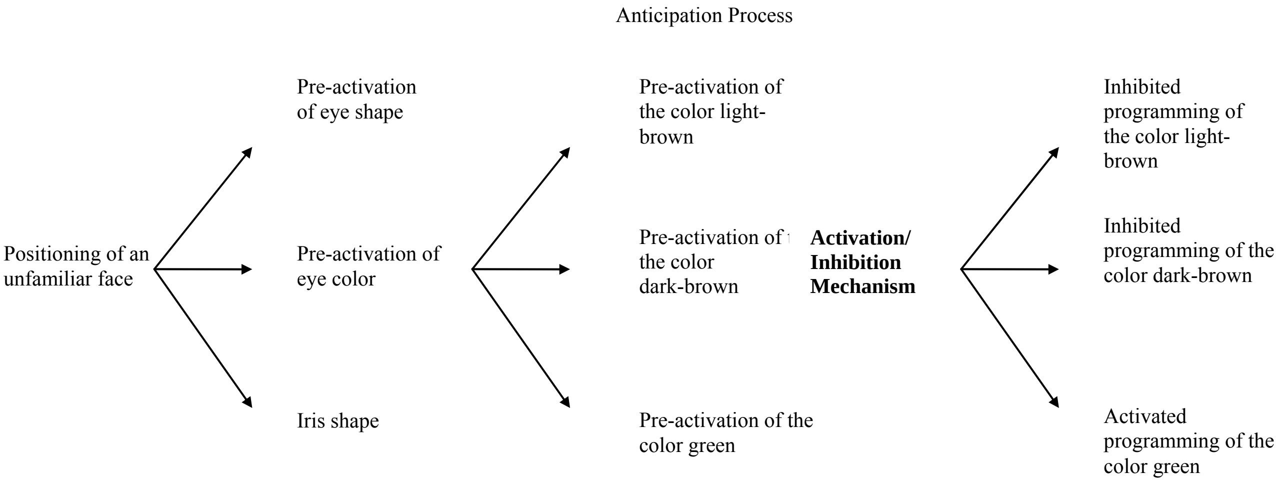


Figure 7. Activation/Inhibition mechanism within the anticipation process acting on modal components

Both ways through which the prefrontal cortex makes the choice depend on the fact that the map selection of perception is more general than the modal selection of mental representation.

Consider, for example, the color of eyes. The map memorized in the inferior temporal cortex is common to all the colors we have perceived so far. This map can be considered on all accounts as the color map (in general). It becomes the green map when, from the F4 area, this specific color is associated to this map.

The same can be said for all the other maps, each of which can be associated to various elements of the areas of primary focalization. When we pre-activate and select the color of a stranger's eyes, or even the color of John's eyes during perception, this pre-activation and selection is performed by using a general map. Focalization takes place on the basis of this map. If we mentally represent the color of a stranger's eyes or John's eyes, the choice is made among the modal components (light brown, dark brown, green, etc.). If "green" is chosen, this specific color will be made conscious through mental representation.

7) Procedural memory and typology of blocks

a) Procedural memory

The two selection processes - map (perception) and modal (mental representation) selections - generate two distinct positioning processes. While the former is a process of unconscious, automatic positioning, the latter is a conscious process of positioning.

Procedural memory is related to automatic positioning. Therefore, perception is supported by procedural memory. Using maps, this memory acts on a general level with respect to the multiple modalities that can be perceived. It can *proceed* toward the image of *a* face that will be made specific only by the area of primary focalization.

When we perform an *imitation* for the first few times, we execute a *voluntary movement* with the help of mental representation. For example, we hear a sound, represent it mentally and activate phono-articulation to reproduce it. In this case, the mental representation of sound acts as a guide to voluntary phono-articulation. With practice, imitation becomes automatic since mental representation is no longer used, and the anticipation of maps is adopted instead.

b) Deterministic and probabilistic blocks

The blocks can be further divided into "deterministic blocks" and "probabilistic blocks". Deterministic blocks, for example, are those characterized by a temporal link between two events: "pressing the switch" and "turning the light on"; probabilistic blocks are those connecting three events in a temporal and logical link (the conjunction "or") two of which are alternative to each other: "throwing a coin", "getting heads" or "getting tails" (Fig. 8 and 9).

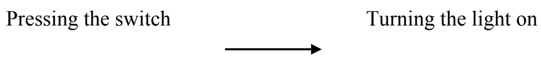


Figure 8. Determinist block related to the pressing the switch and turning the light on

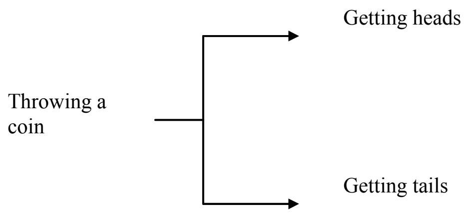


Figure 9. Probabilistic block related to the throwing of a coin and getting "heads" or "tails"

A deterministic block is hardly ever supported by a mental representation of the second event. A probabilistic block is sometimes supported by a mental representation of alternative events, in this case heads or tails. In other words, a block generates constraints which determine the result of positioning in time and/or space. These constraints can allow for either one alternative (deterministic block) or several alternatives (probabilistic block). The numerical sequence (1→ 2→ 3→ 4→ 5→ 6→ etc.) is a block characterized by the positioning and grouping of "objects" in time. This block generates deterministic constraints. Number 2 cannot be followed by number 4, and number 5 is inevitably followed by number 6. Some temporal groupings are circular, such as, for example, the four Seasons (Fig. 10).

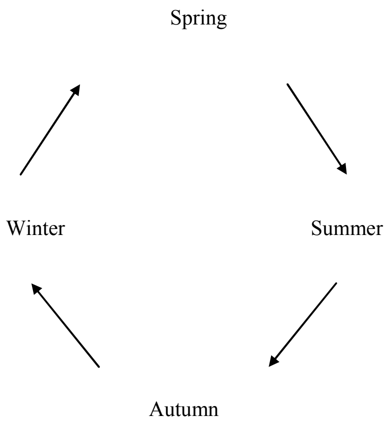


Figure 10. Deterministic grouping of the four seasons of the year

8) Attention

a) Attentional selection

"Attentional selection" is usually considered to be the primary act of perception. The hypothesis being put forward here is that "positioning" is the primary act of perception. However, the "attentional selection" hypothesis is not in contrast with the "positioning" hypothesis since the positioning process is composed of the following sequence of mental activities: anticipation, programming, execution and verification. In anticipation, an "activation/inhibition mechanism" which acts on the mnestic data that are pre-activated by conscious perceptions is thought to exist. Let's imagine that we are looking at (positioning) a room: we will see the objects in it, but we will not consciously perceive them because it is the whole room that is being perceived. After perceiving the room, the objects previously *seen* (but not perceived) will be pre-activated at a mnestic level. Therefore, what we next perceive will depend on which preactivated data are selected after the perception of the room. For each specific object – such as a chair - we can select some features, such as its shape, color, etc.

This process is similar to the one hypothesized by Treisman (1991) in her investigations on attention where she distinguished between *salience maps* (referring to the object as a whole) and *feature maps* (referring to shape, color, etc.).

The activation/inhibition mechanism can select an object, for example a table, after a room has been selected. In this case the room is considered as the "background" of the table which is the "figure". Now, the "figure" can be said to be separated from the "background" through a process of "attentional selection".

Generally, the primary function of our mind is supposed to be the "attentional selection" that works by "separating the figure from the background". This supposition assumes that figure and background are "external" to the mechanism separating or selecting them: that is, two "entities" (figure and background) are built by processing neurons, on which an independent mechanism of separation or selection operates. This way of understanding mental processes, which derives from realism, leads us to hypothesize the existence of a homunculus residing inside the brain, who separates those two "entities". My hypothesis is different. Attentional selection takes place through an activation/inhibition mechanism acting within a complex circuit that also includes the selected entities (which are built by processing neurons). Without such a complex circuit, attentional selection would not be possible.

b) Level of attention (*arousal*)

Various positionings are carried out by different circuits. They act in parallel and this functionality allows us to perform several mental activities at the same time. When we are driving our car for example, we are able to talk with the person sitting next to us. In this case, the ocular-motor circuit, the phono-articulatory circuit, the auditory perception circuit and the motor circuit for the limbs (together with the somato-sensitive circuit) operate simultaneously. Furthermore, the auditory perception circuit operates thanks to at least two parallel subcircuits: the first positions the sounds of language, while the second positions sounds coming from outside. All these circuits work at a low level of attention (arousal), giving origin to various "streams of consciousness" that run across our minds. The level of attention of those circuits remains low for as long as what is anticipated is followed by the expected sensory information (hypothesis-verification). Unexpected information such as, for example, a strange noise coming from the engine, abruptly increases the *arousal* of the circuit that "positions" the noise into the space of the engine compartment. The parallel activity of several circuits is possible because of the fact that they work automatically.

9) Oral language

a) Complexity of the "language system"

Each block is controlled by a specific circuit that works in parallel with other circuits. With language, we can have at least four types of blocks: traits grouped into phones, phones grouped into syllables, syllables grouped into words, and words grouped into sentences.

A twofold structure can be hypothesized for each: surface and deep structure (see also later on). Every circuit is made up of modal and spatio-temporal maps, anticipation and programming dynamisms, areas of primary focusing, as well as complex mechanisms processing sensory information. All this gives an idea of the complexity of the "language system".

b) Procedural memory and linguistic activities

Linguistic activities, such as spontaneous speech, listening, reading and writing, are supported by procedural memory. Indeed, the various linguistic circuits use modal maps as selection options. The specific object of oral and/or written language is rarely selected during anticipation. While speaking, for instance, we do not mentally represent a sound before it is produced. If we want to produce the sound "a", our prefrontal cortex will have to select the *modal map* of this sound. The premotor cortex activates the spatio-temporal map that is *automatically* converted into the specific sound by the primary motor cortex and motoneurons. Therefore, linguistic circuits operate at a more general level than mental representation and can act with extreme rapidity.

c) Interaction of phono-articulatory and auditory perception circuits

Oral language is supported by the interaction of two perception/motor circuits: the phono-articulatory circuit and the auditory perception circuit. The phono-articulatory circuit positions the movements of phonatory organs along the temporal axis. This positioning, accompanied by vocal chord vibration, produces linguistic sounds. The auditory perception circuit positions sounds produced by our or other people's phono-articulatory system along the temporal axis.

The difficulty that children face in articulating sounds comes from the fact that phono-articulation depends also on the positioning of the auditory perception circuit. We first acquire the ability to listen and then the ability to speak; in fact, deaf newborns cannot speak. Phono-articulation is thus structured in two levels. The first level consists in positioning the articulatory organs in time; the second level consists in positioning sounds in time. In other words, phono-articulation is also programmed on the basis of the anticipation of sound position in time. This position depends on the activity of the auditory perception system and the auditory mental representation (mental representation is, however, present only in the learning phase. Subsequently, the process becomes automatic by using map instead of sound anticipation). In other words, the positioning of sounds in time is anticipated, programmed, executed and verified by the auditory perception system. The same positioning of sounds in time (obviously carried out by different populations of neurons) is anticipated, programmed, and executed by the phono-articulatory system. The difference between these two kinds of positionings is that the former is a focusing movement, while the latter is a movement made by the primary motor cortex by means of the intervention of motoneurons. The verification of phono-articulation by the phono-articulatory system only applies to the position of phonatory organs in time (that is, the first level). The position of sounds in time produced by the phono-articulatory system is verified by the auditory perception system, which re-positions sounds during the listening act (Fig. 11).

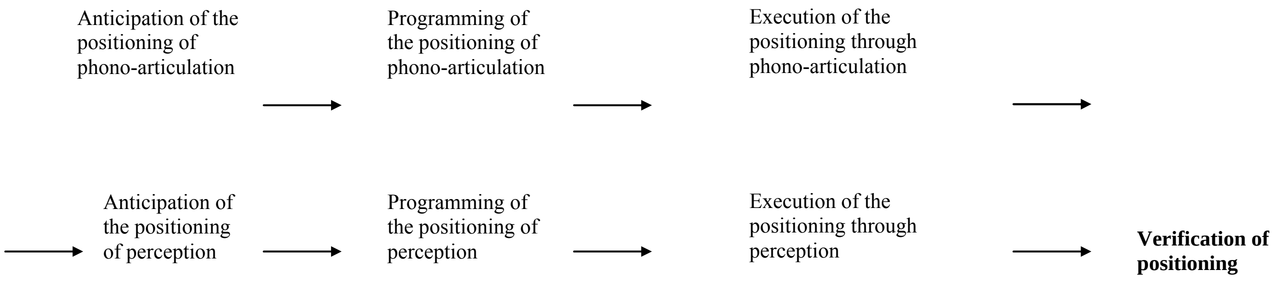


Figure 11. Interaction of the phono-articulatory circuit and the auditory perception circuit

d) Modal maps, temporal maps and dynamisms in oral language

It is known that the memory of positions and "objects" is organized in maps and dynamisms that form blocks (maps of blocks can be also achieved through the process of filling). Maps and dynamisms of blocks make the anticipation and programming of both the auditory perception system and the phono-articulatory system possible.

At both the auditory and phono-articulatory levels, there are blocks of phones, syllables, words and sentences. As to the first type of blocks, that is, of traits in single phones, pronunciation and, above all, the listening of consonants is difficult without the support of vowels. In fact, the pronunciation of the letter "p" is /pi:/. Therefore, for the sake of clarity, the blocks of words forming sentences, phones forming syllables, and syllables forming words will be considered in detail.

e) Surface and deep structures of language

Language is organized in blocks that are temporally connected. This connection can be "linear" or broken down into "groups and subgroups". A linear connection is, for example, the temporal link of the days in a week: Monday – Tuesday – Wednesday – Thursday – Friday – Saturday – Sunday. The connections in language can be both linear and by groups and subgroups. When sounds are linearly connected we have a surface structure. When sounds are connected by groups or subgroups we have the deep surface.

Linear connections characteristic of the surface structure do not depend on meanings. Sounds are connected together in terms of the way they are pronounced and/or listened to. On the contrary, connections by groups and subgroups of the deep structure (phrases) depend on meanings. For example, the words "leaf" and "green" designate an "object" and a "feature". "Leaf" (the object) and "green" (the feature) are characterized by the fact that their spatial connection is so tight that, often, the two spaces they occupy overlap. This is the reason why, when blocks are built, "leaf" and "green" tend to form a single subgroup.

Moreover, the feature can be related to the object by means of the "reference-referred" relation, in which an element, the "reference", is considered as being more important than the other, the "referred" (in our specific case, the object usually acts as the "reference" while the feature acts as the "referred"). This relation is created by means of "meta-positioning". Meta-positioning can only occur after positioning. After both elements have been positioned, the representational circuit passes (positions) from the reference to the referred.

Language conveys the reference-referred relation and the various groupings that characterize objects and/or presentiated things through words. That is, just as object and feature form a subgroup, in which the former acts as the reference and the latter acts the referred, noun and adjective ("leaf" and "green") form a phrase (subgroup) where the noun acts as a reference and the adjective acts as a referred. These words, on the basis of their meaning, form a "subgroup" inside the sentence (group). The linguistic subgroup "green leaf" is called "*noun phrase*" because, between the two linguistic terms, the *noun* "leaf" is the reference of the *adjective* "green". All noun phrases are created through this process.

f) Sentences

Fig. 12 shows the surface structure of the Italian sentence "vado a casa" (I go home).

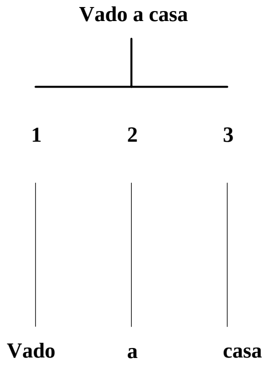


Figure 12. Surface structure of the Italian sentence "Vado a casa"

The three words occupy a position along the temporal axis that is characteristic of the Italian language, as well as some other languages.

In the Italian language, adjectives come nearly always after nouns; in English, adjectives come before nouns (Figs. 13 and 14).

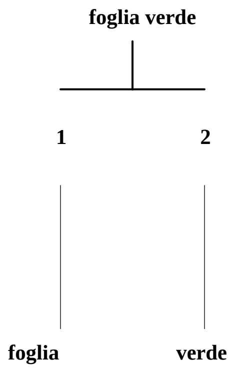


Figure 13. Surface structure of the block "foglia verde"

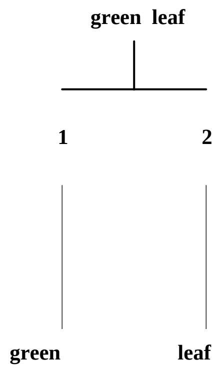


Figure 14. Surface Structure of the block "green leaf"

The position of elements in the surface structure of languages is automatically created through procedural memory.

When creating a deep sentence structure, elements are grouped into pairs. Each group generates a meaningful block (of words) that in turn can be grouped together with another word or another block. For example, in the Italian sentence “Vado a casa” (I go home), the two elements “a” (to) and “casa” (home) are grouped in the meaningful block “a casa”. The element “vado” (I go) is grouped with “a casa” and together they form the sentence “Vado a casa”. Starting from the block “Vado a casa”, it is also possible *to fill* the block “a casa” by positioning the two elements that form it, that is “a” and “casa”.

The deep structure of language involves the meta-positioning and grouping of successive blocks (Fig. 15). The numbers in the figure indicate meta-positioning: “casa” (2) refers to “a” (1) (reference); “vado” (1) is the reference of “a casa”, which is the referred.

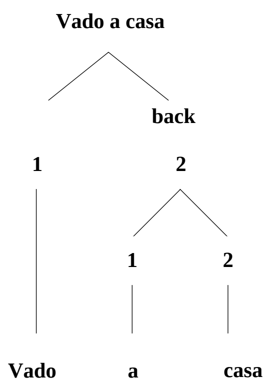


Figure 15. Deep structure of the sentence “Vado a casa”

g) Syllables

In my opinion, syllables also have this twofold structure, surface and deep. In both structures, there are three elements composing the syllable: the “onset”, that is, the consonant or consonant cluster usually preceding the vowel, the “nucleus”, which is a vowel, and the “tail”, that is, the consonant or consonant cluster following the vowel. For example, in the syllable “cat”, the onset, nucleus and tail are “c”, “a” and “t”, respectively. When the consonant preceding or following the vowel is missing, it is replaced by a pause. Fig. 16 shows the surface structure of the syllable “cat”.

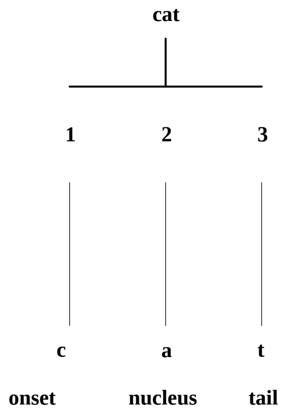


Figure 16. Surface structure of the syllable "cat"

The deep structure of the syllable "cat" is formed by two groupings (or "blocks"). The first is represented by the nucleus (a) and the tail (t); they form the rime. The second grouping is represented by the onset (c) and the rime (at); they form the syllable (cat) (Denes et al., 1996). The "reference-referred" relation can also be found in the structure of syllables. Indeed, syllables have an element which is more important than any other and can be understood as a reference: the vowel. It is the vowel that carries the sound and supports the consonants and consonant clusters. That's why in the rime the reference is a vowel, while the referred is the consonant; in syllables the reference is the rime containing the vowel and the referred is the other consonant (Fig. 17). The numbers in Fig. 17 indicate the reference (1) and the referred (2). A rime is a grouping where the nucleus is the reference and the tail is the referred; a syllable is a grouping where the onset is the referred and the rime is the reference.

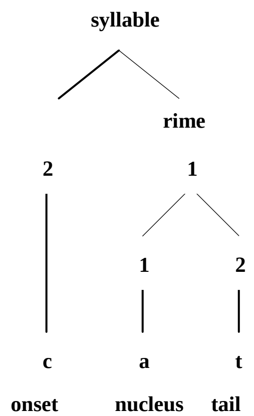


Figure 17. Deep structure of the syllable "cat"

h) Words

The twofold structure, surface and deep, and the "reference-referred" relation also characterize words. Words are formed by groups of syllables. Within words, syllables can be distinguished by their accents. Most probably the stressed syllable acts as a reference for the non-stressed syllable. Fig. 18 shows the surface structure of the Italian word "coperta" (blanket), while Fig. 19 shows its deep structure.

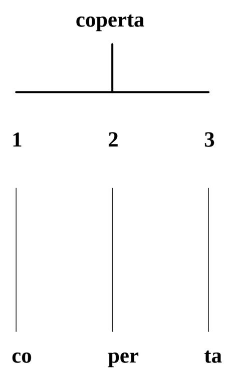


Figure 18 – Surface structure of the Italian word "coperta"

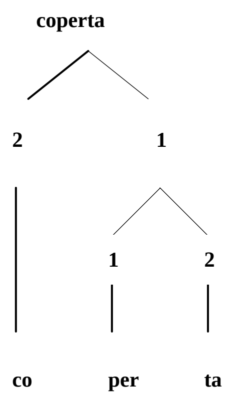


Figure 19 – Deep structure of the Italian word "coperta"

Fig. 19 shows us that the meta-positioning depends on the stressed syllable "per", which acts as reference in the block "per – ta"; in the block "co – perta", the reference is "perta" because it contains the stressed syllable.

i) Wernicke's area and Broca's area

Maps are stored in posterior areas, particularly in Wernicke's area we find modal maps of the auditory perception system and the phono-articulatory system; in some of the parietal areas spatiotemporal maps of both systems are memorized. As far as the memory of dynamisms is concerned, it is very probable that the dynamism of *anticipation* for both systems is stored in Broca's area, while the dynamism of phono-articulatory *programming* is stored in the supplementary motor area.

Subjects suffering from Wernicke's aphasia (Wernicke, 1874) show a deficit in several cognitive functions related to language. Their speech is fluent and paraphasic, but they show deficits in auditory comprehension and repetition. They also show difficulties in understanding written and oral language; furthermore, they have some problems in reading, repeating, speaking spontaneously, and writing (Basso and Cubelli, 1996). These subjects often use a slang full of neologisms that cannot be understood by the listener; moreover, they are not aware of the mistakes they make. This is probably due to the damages of modal maps both in the auditory perception system and the phono-articulatory system.

In people affected by Broca's aphasia (Broca, 1861), their dynamism of anticipation is impaired (selection, retrieval, etc.). However, they show fewer difficulties in comprehension (Martin, 2003) because modal maps can be activated by sounds coming from the primary auditory area. It must be noticed that Broca's area contributes to the positioning of sounds along the temporal axis created by the auditory perception system. This implies that subjects suffering from Broca's aphasia may not understand sentences (Grossi and Troiano, 2005) since the positioning of sounds in time is more relevant in understanding sentences than in understanding single words.

10) Relations

In my opinion, mental functions are created through the positionings performed by several neuronal circuits. By being reiterated in pre-determined positions (meta-positioning function), these positionings give rise to various relations. Similarly to what happens in language, the meta-positioning performed after positioning generates a reference-referred relation, the *reference* being the first element to be meta-positioned, and the *referred* being the second element to be meta-positioned.

The kind of relation depends on the "objects" that are kept present. Let's suppose we have positioned two objects in space, for instance a table and a lamp. They are grouped in space. If, after a single act of focusing, we keep present both of the objects positioned in space (which are built simultaneously in the area of primary focalization) and meta-position both of them, we can generate the over/under or under/over spatial relation (Fig. 20).

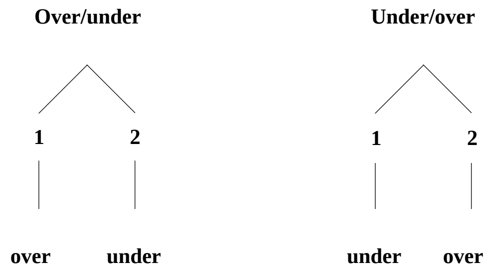


Figure 20. Spatial relations over/under and under/over obtained through meta-positioning

Objects are singled out of their context by means of perception or mental representation and a spatial relation is established. We can have: the lamp (reference) over the table (referred) or the table (reference) under the lamp (referred). The other spatial and temporal relations can be obtained in the same way: inside/outside, right/left, forward/backward, before/after, etc. Obviously, in temporal relations, presence keeping involves two objects that are grouped in time.

Relations can also be produced outside the spatiotemporal context, as is the case with correlations in language. In this case, meta-positioning is performed on modal components that are individually selected, that is, outside the spatial and/or temporal block. For example, I can select the modal components "light" and "dark" and meta-position them, thus producing the "heavy/light", "big/small", "tall/short", "cold/hot", "sad/happy" relations etc.

If the two selected elements are an *object* and one of its *features*, we obtain the *adjective-noun* relation: "green leaf", "bitter pill", where the noun is the first element to be positioned.

We said that the building of blocks occurs on a spatial and/or temporal basis. This is true for positioning. Through meta-positioning, however, we can build some other blocks, that is, *classifications* and *correlations of language*. We have already dealt with correlations. Classifications are characterized by the fact that the selected and meta-positioned elements are *undifferentiated entities*. For example, we can meta-position one "apple" and one "apple". In this case, we obtain "two apples". We can also repeat the meta-positioning; the result will be "three apples". Similarly, we can group "few apples", "many apples", "several apples". In this classification, the positioning order is negligible. Entities grouped into blocks are, indeed, "equal". The *class* is a block where equal (undifferentiated) entities are kept together by meta-positioning: the class of mammals, vertebrates, carnivores, etc.

Conclusion

This paper deals with perceptual-motor circuits. By means of a new hypothesis as to their function, I have tried to put forward a new theory aimed at shedding light on mental processes since it is believed that these processes can be explained only by investigating circuital functions.

With this aim I have focused mainly on the function of perceptual-motor circuits, while not disregarding some topics in the field of Neuropsychology. Indeed, the more I succeed in explaining mental functions through circuital activities, the more the proposed theory gains credit

In order to create mental processes, neural circuits need to possess some fundamental features and need to:

1) function as a small-scale laboratory where information coming from sensory receptors is hypothesized and verified, through a process of anticipation, programming and execution;

2) collect and store sensory data, but also integrate these, thus succeeding in improving through experience;

3) allow us to explain how information is collected, stored and used in everyday life: this would avoid any discontinuity among “objects”, “selection”, “memory”, “identification”, etc.

As far as memory is concerned, my interpretation of “procedural memory” is that it is involved in the anticipation of “maps”. In this sense, procedural memory (typical of movements and perceptions) differentiates from the memory that is related to mental representation circuits.

I have also hypothesized that mental processes take place at two “levels”. At the first, more simple level sensory information is elaborated by populations of neurons; at the second level “positioning” is performed by circuits. This circuital architecture is common to both motor and perceptual circuits.

Positioning can be reiterated (function of “meta-positioning”). Through “meta-positioning” we obtain spatial, temporal, modal “relations”, etc. Furthermore, meta-positioning also generates other meaningful blocks: classifications and correlations of language.

These topics have been addressed from a general point of view but require further investigation. For example, the elaboration process, which has been investigated only in relation to the sensory systems and primary areas, surely includes the first- and second-order associative areas as well as the frontal areas. Moreover, the function of positioning does not modify only the areas of map anticipation and programming (associative and frontal cortexes), but certainly also plays a major role in the organization of both the primary areas and sensory systems. The way that primary, associative and frontal areas interact is to be analyzed in detail and how the various circuits interact to form the unity of individual consciousness also needs to be explained.

References

Basso, A., Cubelli R. (1996). "La clinica dell'afasia". In G. Denes e L. Pizzamiglio (a cura di), *Manuale di Neuropsicologia*. Zanichelli. Bologna.
Broca, P. (1861). "Perte de la parole. Ramollissement chronique et destruction partielle du lobe antérieur gauche du cerveau". *Bulletin de la Société d'anthropologie, 11: 235 – 237*.
Ceccato, S. (1964). *Un tecnico fra i filosofi. Vol. I. Come filosofare*. Marsilio. Padova
De Renzi, E. (1996). "Le Agnosie". In *Manuale di Neuropsicologia*, G. Denes e L. Pizzamiglio (a cura di), *Manuale di Neuropsicologia*. Zanichelli. Bologna.
De Renzi, E., Faglioni, P. (1996). "L'aprassia". In *Manuale di Neuropsicologia*, G. Denes e L. Pizzamiglio (a cura di), *Manuale di Neuropsicologia*. Zanichelli. Bologna.
Denes, G. (1996). "Disturbi della localizzazione e consapevolezza corporea". In G. Denes e L. Pizzamiglio (a cura di), *Manuale di Neuropsicologia*. Zanichelli. Bologna.
Denes, G., Semenza, C., Magno Caldognetto, E. (1996). "Disturbi fonologici nell'afasia". In *Manuale di Neuropsicologia*, G. Denes e L. Pizzamiglio (a cura di), *Manuale di Neuropsicologia*. Zanichelli. Bologna.
Desimone, R. (1991). "Face-selective cells in the temporal cortex of monkeys". *Journal of Cognitive Neuroscience, 3: 1–8*.
Grossi, D., Troiano, L. (2005). Neuropsicologia dei lobi frontali. Il Mulino Bologna
Hubel, D. H., Wiesel, T. N. (1968). "Receptive fields and functional architecture of monkey striate cortex". *The journal of physiology, 195: 215 – 243*.
Kandel, E., Jessel, T. M. (1991). "Il tatto". In E. R. Kandel, J. H. Schwartz, T. M. Jessel (a cura di), *Principi di neuroscienze*. Seconda edizione. Ambrosiana. Milano.
Kelly, J. P. (1991a). "La funzione uditiva". In E. R. Kandel, J. H. Schwartz, T. M. Jessel (a cura di), *Principi di neuroscienze*. Seconda edizione. Ambrosiana. Milano.
Kelly, J. P. (1991b). "Le basi nervose della percezione e del movimento". In E. R. Kandel, J. H. Schwartz, T.M. Jessel (a cura di), *Principi di neuroscienze*. Seconda edizione. Ambrosiana. Milano.
Leopold, D. A., Logothetis, N. K. (1996). "Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry". *Nature, 379: 549-553*.
Lissauer, H. (1890). "Ein Fall von Seelenblindheit nebst einem Beitrag zur Theorie derselben". *Archiv für Psychiatrie, 21: 222 – 270*.
Livingston, M., Hubel, D. (1988). "Segregation of form, colour, movements and depth: Anatomy, physiology, and perception". *Science, 240: 74 –749*.
Logothetis, N. K., Leopold, D. A., Sheinberg, D. L. (1996). "What is rivalling during rivalry?" *Nature, 380: 621-624*.
Lumer, E. D., Friston, K. J., Rees, G. (1998). "Neural correlates of Perceptual Rivalry in the Human Brain". *Science, vol. 280, n. 5371: 1930–1934*.
Luzzatti, C., Davidloff, J. (1994). "Impaired retrieval of object-colour knowledge with preserved colour naming". *Neuropsychologia 32: 993–950*.
Martin, J. H. (1991). "Codificazione ed elaborazione delle informazioni sensoriali". In E. R. Kandel, J. H. Schwartz, T. M. Jessel (a cura di), *Principi di neuroscienze*. Seconda edizione. Ambrosiana. Milano.
Martin, R. C. (2003). "Language processing: functional organization and neuroanatomical basis". *Annual review of Psychology, 54: 55–89*.
Mason, C., Kandel, E. R. (1991). "Le vie visive centrali". In E. R. Kandel, J. H. Schwartz, T. M. Jessel (a cura di), *Principi di neuroscienze*. Seconda edizione. Ambrosiana. Milano.
Perret, D. I., Mistlin, A. J., Chitty, A. J. (1987). "Visual neurons responsive to faces". *Trends in Neuroscience, 10: 358-364*.
Pick, A. (1902). "Zur Psychologie der motorischen Apraxie". *Neurologische Zentralblatt, 21: 994–1000*.
Pick, A. (1904). "Zur Symptomatologie der linksseitigen Schaelefenappelnatrophie". *Monatsschrift furPsychiatrie und Neurologie*, 16: 378–388.
Robinson, G., Blair, J., Cipollotti, L. (1998). "Dynamic aphasia: an inability to select between competing verbal responses?". *Brain, 121: 77-89*.
Sims, A. (1997). *Introduzione alla psicopatologia descrittiva*. Cortina. Milano.
Treisman, A. (1991). "Search, similarity and the integration of features between and within dimensions". *Journal of Experimental Psychology: Human Perception and Performance, 17: 652-676*.
Ungerleider, L. G., Mishkin, M. (1982). "Two cortical visual systems". In D. J. Ingle, M. A. Goodale, R. J. W. Mansfield (a cura di), *Analysis of visual behaviour*. MIT. Cambridge, Mass.
Vaccarino, G. (1988). *Scienza e semantica costruttivista*. Clup. Milano.

Van Lancker, D. R., Carter, G. J. (1982). “Impairment of voice and face recognition in patients with hemispheric damage”. *Brain and Cognition, 1: 185–195.*
Wernicke, C. (1874). *Der Aphasische Symptomencomplex*. Max Cohn und Weigert. Breslau.