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MOTOR ACTION AND BRAIN PROCESSES: A NEUROSCIENTIFIC PERSPECTIVE

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Abstract
The rapid development of neuroscience has shown how numerous aspects of behaviour reflect the characteristics of the nervous system and how having experiences depends on the interaction between numerous brain functions. In 1996 Rizzolatti's team published an article in the journal Brain entitled "&quot: Action Recognition in the Premotor Cortex&quot", in which they demonstrated the existence of a special class of cells, defined as "mirror neurons". When we perform a movement, we program it based on the objective we have set for ourselves: we perform different gestures and movements based on the act we want to perform, for example, having a cup of tea or clearing the table. There is a close link between motility and thought and that is often reflected by the way our mind works. Mirror neuron activity is not affected by the presence of food or the character of the visual stimulus, but, rather, by acts performed by the experimenter involving and effector-object interaction.

Keywords Mirror neurons, motor action, neuroscience, behaviour.

INTRODUCTION

In the last decades, the interaction between pedagogy and neurosciences has become issue of marked interest. It has to do with asserting the plural complexity of brain functions, which, alongside education sciences, help us scientifically inspect the apparatuses linked to learning mechanisms, emotions and human behaviour.

The rapid advances undergone in the neuroscience field reveal how the characteristic features of nervous system are reflected in the numerous aspects of behaviour and how building experience is deeply affected by the interrelation between the plentiful brain functions.

A better comprehension on brain functions may, thus, lead to a better educational process, especially in those years in which brain takes form on the base of the maturation of the nervous system, where genetic and experiential factors are strongly intertwined. Indeed, base for neuropedagogy is to be found in the concept of neuronal plasticity, that is the capacity of the brain of developing in a slow and progressive way, going through several stages, which have been proven to be genetically determined. Throughout development the brain is in constant interaction with the outside world, through which the individual acquires the so called "cultural imprinting", represented by the acquisition of language, behavioural regulations, moral and symbolic systems allowing the (non – genetic) transmission of the experience1.

Nevertheless, in order for the brain to develop in an optimal way, a constant interaction between the environmental stimulation and the nerve function is necessary. Human brain neural network develops by multiplying connections among nerve cells, thus causing an overlapping of synaptic contacts. "Excess" connections and cells are eliminated via a selective sorting process and the derived synaptic density is further reduced thanks to the interaction with the environment. If the latter lacks, cell death phenomena, whose functions are fundamental for life, may occur. Hence the fundamental importance of the interaction between environment and neural development in the child's growth.

One of the first aspects to be considered is the role motility plays during the growth stage: a quite fundamental one if considered that motor functions are highly represented at the level of both the cerebral cortex and the subcortex structures. These motor actions are one of the outcomes of the significant space devoted to motility, so much so that motion exercise deeply affects child's brain maturation. Motor actions follow precise increasingly coordinated development stages, which depend on "procedural" memories, codifying movement sequences in response to specific situations.

These resembling sequences, defined "scripts", quickly enhance a range of complex muscle alignment sequences, aimed at reproducing adults' facial expressions. These muscle or "body" memories constitute the starting point of the following linguistic learning processes, which, in step with the others, are based on motor sequences. These are quite similar to the hand or head coordination movements and are fundamental for the coordinated creation of significant sounds.

Cognitive processes and motor actions

According to Maria Montessori2, motility and thought are strictly interwoven and that is quite evident from the way our mind works and reacts. A second worth noticing aspect is the role played by executive functions – attention, memory, task planning and execution capability – in the course of development. Colorado University developmental psychologists Naomi Friedman and Akira Miyake3 proposed an executive functioning model, based on a functional triad: inhibition, mental flexibility, update.

Selecting some of the many incitements our mind continuously receives is fundamental, in order to make significant experiences, memorise, learn. That is particularly important for babies, whose mind is open to a variety of changes and sensations. This process entails a selective attention, a slowly developing capacity, which goes from a handful of seconds, in the first few weeks and years of life, to a progressively longer time. Inconstancy and short attention span are also to be linked to a scarce maturity of motivation mechanisms, which contribute to keep attention and counteract fatigue. Attentional processes are different during development: children not only show to have a quite transient attention, but they are also not capable of carrying out two tasks simultaneously. Hence, if distracted from a task, they show to have some difficulties in going back to it and focus on it once again, and they are also quite likely to lose that experience due to the insufficient memory skills.

Older children show to have a quite short attention span too: a 6-7–year-old child starts being distracted after only minutes, while a 15-16-year-old boy is able to pay attention for about 30-45 minutes. Learning abilities may so be improved by resorting to short experiences, alternating sensory topics and "codes": for instance, with a pre-school child it is important to seize the moments of attention and make each experience recreational, while primary school kids need to take frequent breaks and change the object of their attention.

Another aspect deeply affecting attention is anxiety: in cases where a child or a teenager has some concerns about something troubling or is dealing with family tensions etc., attention is reduced, with the mind appearing to be elsewhere or in a state of confusion. Broadly speaking, it is worth noticing that nowadays children and teenagers are deluged with instantaneous and rapid messages (TV, videogames): In many videogames there are about 100 images, rapidly following one another and, as a consequence of that, situations which require a sort of slowness are taken with intolerance. Hence, the necessity of teaching them the importance of slowness and concentration: observing animal behaviour or natural seasonal variation, taking care of plants are all good indirect strategies, quite useful to acquire a new approach to time and the surrounding reality.

Attention and learning, above all at school, are not just linked to mental processes or focused strategies, though. For example, after 15-20-minute aerobic physical activity (running), the ability to concentrate considerably improves: schools should take that into consideration when organising the school schedule for students. It would be advisable to start the learning day with a physical education class or, at least, to use it as a sort of break between one class and another. Broadly speaking, children

with proven attention-deficit disorder have shown to have a better ability to concentrate after motor control exercises.

A better comprehension of brain functions and development may, in substance, help pedagogy be based on concrete knowledge. A neuroscientific approach to education is not to be seen as a replacement for pedagogy, but as a sort of indication to parents and teachers on how many experiences are strictly linked to brainstem and its functions and how the awareness of these dynamics may result in a better educational process. Strictly interwoven with brain and mind maturation, pedagogy helps regulate educational intervention. Studying the nerve bundles our brain is composed of appears, so, to be fundamental in the different stages of development and education.

Social neuroscience has identified a series of cerebral areas, capable of empathically activating brain, namely denoting the activation of other people's brain. These brain structures, named mirror neuron systems for their peculiar features, allow us not only to imitate other people's overt behaviour, but also to partially understand emotions and intentions. They are a particular class of neurons, originally found in the ventral premotor cortex and in the inferior parietal lobule of macaques, which have the peculiarity of firing both when an organism voluntarily acts and when the organism observes the same action. The discovery of mirror neurons has confirmed social psychology theories on imitation and empathy pervasive automation. The vision of other people's motor patterns is not the only thing triggering mirror neurons activity. Indeed, the observation of emotional reactions causes a specular reaction too: the perception of other people's emotions may determine in the observer the activation of the same cortical region used when that kind of emotion is personally experienced [Rizzolatti, Vozza 2008].

Both direct and observed experiences cause in people an activation of the same cortex areas. Besides, mirror neurons do not fire on the basis of the simple observed movement, but based on its aim. Understanding other people's actions and the reasons behind is a distinctive feature of our species allowing the interaction with our counterparts. Until a few years ago, mechanisms at the base of these cognitive faculties were still unknown, but the discovery of mirror neuron systems in monkeys and humans has shown, for the first time, a neurophysiological mechanism able to clarify many aspects about our capacity of relating to the others4.This particular cell class was discovered at the University of Parma during a series of lab experiments carried out by Giacomo Rizzolatti and a team of neuroscientists.

The first experiment was carried out in 1988: the aim was to understand how premotor cortex neurons were able to control the grasping activity in macaques. The method used for the experiment to be carried out was based on the "single unit recording": microelectrodes, necessary to collect action potentials, were inserted in the brain of the macaque, in order to measure the electrical activity of each neuron whilst the animal accomplished a specific task5.

Following the studies and the discovery made, researchers started another experiment with the aim of "recording the reaction to the observation of actions in the brain of monkeys6". This time,

researchers were personally involved. They had to perform a series of motor actions in front of the animal: to hand out a small bite of food to a colleague, to pick it up or to put it in the breast pocket; to break or rip up specific objects; raise their arms, gesture, mime actions or grab objects with various instruments. This experiment highlighted two aspects:

1- most neurons discharged in the right moment the macaque performed an action, so proving that F5 is a motor area

2- Visual response was triggered by both the simple objects and the observation of other actions being performed.

In cases where the visual response was triggered by the observation of other actions performed, researchers noticed that there was a close correlation between the kind of actions preferred by the cell during the observation and the execution of the task: if a cell discharged when the monkey acted with a grip throughout the whole hand, the cell discharged the same way when observing an action with the same grip. In their article published in 1992, Rizzolatti's team explained the reasons why only some motor cortex cells could react to the actions object of observation:

One of the fundamental actions by premotor cortex is retrieving appropriate motor actions in response to sensory stimuli. If we consider the rich social interactions in a cluster of monkeys, an individual's understanding of the actions performed by others must be a very important factor in determining the choice of actions […] [this idea] is in good agreement with the conceptual framework of the theory on the function of the premotor cortex7.

In the article published by Rizzolatti's team in 1992, two studies were cited: the first in reference to limb apraxia, the second in reference to the motor theory of speech perception. In the first case, it has been shown that limb apraxia makes it particularly difficult to execute voluntary limb movements and, similarly, to understand the limb movements of other subjects. In the second case, instead, the motor theory of speech claims that we understand the spoken language thanks to particular reconstructions taking place in our brain: according to this theory, in fact, it is the motor gestures which generate the perceived sounds.

Thanks to the contribution of these two studies, it has been demonstrated that the perception of motor (and locutionary) acts depended on the motor system:

Although they do not demonstrate motor theories of perception at all, our observations indicate that in the premotor cortical areas there are neurons endowed with the properties required by such theories. Interestingly, the anatomical location of […] F5 corresponds to that of Broca's area in the human brain8.

The connection between the F5 region present in the monkey brain and Broca's area in the human one proved to be fundamental, since it was believed that the F5 area was the equivalent of Broca's

area (language articulation site, as demonstrated by the French neurologist Paul Broca in the late 1800s)9.

Based on these observations, researchers understood that the connection between Broca's area and the F5 region could not be real, as monkeys, not speaking, do not have an area of the brain dedicated to the articulation of language.

In 1996 a new article entitled "Action Recognition in the Premotor Cortex was published by Rizzolatti's team on the scientific magazine "Brain". In it the team introduced this cluster of cells: over the years the team carried out further experiments, quite similar to those of the past years, but involving, this time, two monkeys. This was particularly relevant in the field of neuropsychology, because it demonstrated not only the existence of this special class of cells, defined as “mirror neurons”, but also because it decisively supported the importance of this type of neurons in human cognition and behaviour.

The demonstration of a mirror system in human beings was given by three types of tests, two obtained by Rizzolatti’s team and one based on the literature:

1- Transcranial Magnetic Stimulation (TMS): it had shown that when humans observe seizing movements, their hand-area motor excitability remarkably increases. […]. When subjects observed someone else grasping an object, PEMs (evoked motor potentials) were greater than the ones obtained with the observation of only objects. The authors of the study interpreted the result as evidence that observation of actions automatically activated the motor system involved in the grasping action.

2- Positron Emission Tomography (PET): it had shown that when humans observe actions performed by others, there is an increase in neural activity in Broca’s area, the region believed to be the human homologue of area F5 in macaques10. PET is a functional brain imaging method that records brain activity by measuring regional changes in blood flow: when a brain region is active, blood flow to that region increases to provide the metabolic fuel, oxygen and glucose, needed to sustain the additional activity. The discovery of increased blood flow in Broca’s area during action observation was consistent with the idea that the human motor system is active during action perception11.

3- “[…] patients with lesions of the frontal lobes, who showed deficits in the recognition of mimicked actions. Neurological literature documents that, sometimes, patients suffering from language disorders (aphasias) have difficulty in recognizing mimicked actions. This is clearly relevant to the question of the possible role of mirror neurons, since the recognition of mimicked actions can be interpreted as a form of action understanding”12.

Mirror Neurons and modes of action

Thanks to the discovery of mirror neurons, a neuronal mechanism has been identified that allows to immediately combine the visual description of an action with its understanding and execution. Understanding an action from a neuronal perspective means that the brain has the ability to obtain an internal description of an action and use it to plan future motor behaviours. The analysis of the F5 area in the premotor cortex of the macaque has shown how the majority of neurons present in this area fire during the execution of motor acts, for example grasping, holding, manipulating and how a part of them also responds to visual stimuli. These neurons, already known before the 1990s and called “canonical neurons”, reveal a correspondence between their motor properties (codified grip type) and their visual selectivity (shape and size of the object) 100. These neurons are activated according to the purpose and methods of the action to be performed, they function in a coordinated manner and in sequences. Canonical neurons constitute […] a vocabulary of acts, which corresponds to a reservoir of possible actions. They activate the motor pattern necessary to interact with objects Of course, most of the time, this is just a potential pattern but, in the right moment we decide to actually grasp the object, the pattern is already active and can immediately activate the corresponding motor area muscles13. Canonical neurons make up approximately the 80% of the premotor cortex, the remaining 20% is made up of mirror neurons, which have the ability to fire not only when we plan and perform an action but also when we see it executed by others. In terms of motor properties, mirror neurons selectively fire during specific motor actions and, therefore, are not distinguishable from other F5 neurons.

However, unlike canonical neurons, the behaviour of mirror neurons does not seem to be influenced by the presence of food or the character of the visual stimulus, but rather by the acts performed by the experimenter, which involve an effector-object interaction. If we use the visually codified motor act as a distinctive criterion, it is possible to divide the mirror neurons into different classes: mirror neurons for grasping – they fire when the monkey observes the experimenter's hand approaching the object and prefigures the grasp. They also discharge when it is the animal which grabs the food (hand- related neuron discharge).

- Mirror neurons for manipulating: they discharge in the moment the monkey observes the experimenter touching and moving an object with his fingers. The discharge begins before the experimenter's fingers touch the food and stops when this (the grape) is put back into the cage; when the experimenter mimics the movement of the food in the absence of food, the neuron fires more weakly

- Mirror neurons for holding: they discharge when the monkey observes an object held in the experimenter's hand. The discharge ceases as soon as the experimenter removes his hand from the food14.

- Mirror neurons for placing: they fire in the moment the monkey observes the experimenter placing an object on a support.

- Hand-grasping mirror neurons: they react to the sight of one hand moving towards the other, while the latter is holding an object15.

The comparison between the visual responses and the activity during the motor acts allows us to understand the congruence existing between the motor act, encoded by the neuron, and the observed motor act, which is effective in activating it. There are two different types of congruence: congruence both in a strict and a broad sense. The former shows an exact correspondence between the observed and the performed action, the latter shows a connection between the acts encoded by the neuron in visual and motor terms, even though they are not identical to each other.

The "communicative" mirror neurons respond when the monkey observes communicative gestures performed with the lips or tongues: they are gestures that express an invitation to relate to another individual. The motor response of this type of mirror neuron is more complex than the one performed by the "ingestive" neuron: the neuron fires as the monkey produces both communicative and ingestive gestures. For instance, a neuron reacting to the observation of lipsmacking (alternate mouth opening and closing slight movements, accompanied by tongue protrusion and retraction ones) also responds when the monkey performs a sipping action: Indeed, in both gestures the actions of opening and closing the mouth alternate. Furthermore: communicative mirror neurons may be important for a better understanding of the evolution of language, as they are phylogenetically the first neurons with communicative significance to appear in the lateral cortex. […] With communicative mirror neurons […] we witness the appearance in the lateral cortex of neurons which mediate the voluntary control of gestures with affiliative meaning, important especially for the interpersonal communication16.

CONCLUSIONS

Hence, following the discovery and classification of mirror neurons, it could be easily thought that their primary function is imitation. On the contrary, the main function of these neurons is understanding other individuals' actions and intentions. When we make a movement, we programme it on the base of the objectives we have set ourselves: we perform different gestures and movements based on the act we want to perform, for example having a cup of tea or clearing the table. The goal we want to achieve conditions the type of movement from beginning to end, and this is the reason why, when we reproduce the observed action in our brain, we can understand its meaning and intention. However, the comprehension of other people's actions is not only due to the activation of mirror neurons. We are able to rationally understand others' intentions, thanks to context information and deductive reasoning. Nevertheless, comprehension via mirror neurons is particularly important and effective for its being intimate, corporeal and immediate, all aspects related to its arising from an internal simulation of the movement and is simultaneous with what we observe17.

Internally simulating the action does not mean repeating every action we observe: our motor behaviour is inhibited or activated by a particular area of the prefrontal cortex, favouring, when necessary, imitative processes. Imitation can be voluntarily activated, for example when we learn to play an instrument. In the learning process, the student observes the teacher's actions, breaks down the movements into elementary motor acts and assembles them to obtain the most complex movement he desires to perform. Imitation may also be involuntarily activated, especially when we find ourselves experiencing "warm" emotions and situations directly involving us. Finally, unconscious imitation leads us to imitate the behaviour of the people we care about and who are closest to us. By imitating them, we are able to identify with them and convey a sense of commonality.

It has been shown that the mirror neuron system is also involved in the observation of other people's emotions and pain. Thanks to the neuroimaging technique, it has been discovered that the same cortical areas are stimulated both when we feel pain ourselves and when we see someone else experiencing the same sensation. When we see someone who is suffering or happy, autonomous and specific neurons are activated, capable of experiencing others' emotion in our body18. By internally experiencing emotions in an immediate and simulated way, we can fully understand what other people feel; our knowledge of other people's experience is "embodied cognition", experience through the body. The discovery of mirror neurons, so, also shows us the neural basis of empathy.

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