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Original Article

Neuroplasticity and motor learning in sport activity

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Abstract
Plasticity is the ability of the nervous system to change structurally and functionally, following physiological, harmful and environmental stimuli. Thanks to a series of non-invasive technologies, such as Transcranial Magnetic Stimulation (TMS), the Motor Evoked Potential (MEP), Magnetoencephalography (MEG), the Positron Emission Tomography (PET), the Functional Magnetic Resonance Imaging (fMRI), the Near-Infrared Spectroscopy (NIRS) and Blood oxygenation level-dependent MRI (BOLD-MRI), and Motion Capture System, it is now possible to study how different physiological and pathological conditions can affect the brain architecture and its functions.Thanks to neuronal plasticity it is possible to obtain alterations that can be useful for both recovering the functionality of areas compromised by a traumatic event (such as the loss of a limb, a stroke or blindness), but are also useful for another fundamental aspect of animal and human life: the acquisition of motor skills, and therefore of motor learning. This is a process that is influenced by experiences, and is crucial for the cortical organization and reorganization phenomena. The experience-dependent conditions such as the physical activity seem to have a prominent role in brain architecture. In fact, the physical activity determines an increase of synapse formation and causes the release of hormonal factors that promote neurogenesis and neuronal function, these phenomena inducing an improvement of neurocognitive functions.The purpose of this work is to briefly summarize the scientific studies that highlight the effect of motor learning on the anatomical-functional modification of the brain,underlining how sport is fundamental to favour the phenomena of neuronal flexibility and the maintenance of a good health.

KeyWords: Plasticity, Neuroplasticity, Cortical Reorganization, Motor Learning, Motor Re-learning, Sport, Physical Activity

Introduction

The connectionist-localization doctrine of brain functions formulated over 100 years ago by Camillo Golgi and Santiago Ramón y Cajal, based on the neuron theory, was the product of extraordinary studies and brilliant intuitions by scholars who worked in the second half of 19 Century and in the first third of the 20th. However, what, not surprisingly, we wanted to define doctrine, was developed before the era of molecular biology and electronic technologies. What the transcription and translation factors were, the G-proteins, the co-transmitters, the extra-synaptic transmission (the so-called volume transmission), was not known at the time, therefore there was the conception of a system much more rigid than what in reality it has proven to be the nervous system.

In 1890 William James, in his Principles of Psychology(James, 1890), first introduced the term plasticity in the field of neuroscience. A few years later, in 1904, Santiago Ramon y Cajal, in his Textura del Nervous System(Ramón, 1899) argues that behavioural modifiability must have its anatomical and physiological basis and was undoubtedly the one who, before any other, was able to intuit some fundamental mechanisms about the functioning of the nervous system.To introduce the concept of plasticity, as it is understood today, we refer to Pasqual-Leone's words: “Plasticity is an intrinsic property of the brain of man [but not only of man] …… maintained throughout the course of the life …… and represents an invention of evolution to allow the nervous system to escape the restrictions of its genome, thus adapting it to environmental pressures, physiological changes and experiences ". …… "that it is not possible to understand normal psychological functions, or the manifestations or consequences of diseases without invoking the concept of brain plasticity".

Cortical reorganization phenomena have been observed, in animals and humans, also in response to cortical lesions: Nudo et al. for example, in a study of cortical microstimulation in monkeys, in which a cortical ischemic infarction had been induced experimentally, they showed a phenomenon of "invasion" of the infarcted area by the adjacent ones that remained unharmed(Nudo et al., 1996).

There are numerous experimental settings and techniques adopted, in animals and humans, to study the mechanisms of learning,and cortical reorganization. Thanks to the Human Brain Mapping technologies currently available, it is possible to address the issue of cortical organization in the context of motor learning (and re-learning).This last process follows a path fundamentally consisting of two phases: in the first there is an

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"unmasking" and strengthening of pre-existing connections, while in the second there is the creation of new connections.

These technologies can be useful both to observe the excitability of the different cortical areas, the Transcranial Magnetic Stimulation (TMS)(Zrenner et al., 2018), the Motor Evoked Potential (MEP)(Quinn et al., 2018) and the Magnetoencephalography (MEG)(Sorrentino et al., 2018), and to evaluate the hemodynamic of these areas the Positron Emission Tomography (PET)(Magan et al., 2019), the Functional Magnetic Resonance Imaging (fMRI)(Guerra-Carrillo et al., 2014), the Near-Infrared Spectroscopy (NIRS) and Blood oxygenation level-dependent MRI (BOLD-MRI)(Van der Linden et al., 2009). They represent a body of non-invasive methods that in recent years have allowed to acquire a significant amount of reliable information, on the cerebral cortex, in normal and pathological conditions, and in different experimental paradigms. There are also other non-invasive technologies, such as Motion Analysis, which are capable of evaluating neuroplasticity processes through the motor outcome, under physiological(Smith, 2017) and pathological conditions(Liparoti et al., 2019)(Sorrentino et al., 2016). Being a very precise instrumentation, it is used in the sports field as well, not only for observation, but also for monitoring the learning processes of a sports gesture, in order to improve the technique and prevent injuries(Ozawa et al., 2019)(Myer et al., 2011)(Napolitano et al., 2018a; 2018b).

The phenomena of neuronal plasticity have been extensively studied, through the technologies mentioned above, in the sports and motor rehabilitation fields. Motor learning is defined as the ability to acquire new motor actions or new movement patterns(Richard & Magill, 2001). Sport and physical activity in general are experience-dependent conditions, which, through movement or observation of movement, contribute to increasing or developing the ability to store information. Sport therefore not only allows the regulation and control of movement with the consequent development of precision and coordination, but also contributes significantly to the phenomena of reorganization of the architecture of the neural networks and therefore also to the phenomena of neuronal plasticity. Scientific research has shown that a series of psychophysiological changes occur both when a motor gesture is actually performed and when it is observed; in fact, it has been shown that the neuronal circuits that are activated when we perform an action are the same ones that are activated when we imagine it. These special neurons, called mirror neurons, are activated both during the execution of an action and during the observation of the execution of a similar action.Therefore, to classic training, it is recommended to combine mental training to acquire and improve the technique of a motor gesture.

Therefore, phenomena of neuronal plasticity can be modulated by movement.In the sports field, for example, it was observed that professional archers revealed a cortical disparity regarding the activation of some brain areas compared to people who had never practiced this sport(Chang et al., 2011). In this brief review, we have summarized the evidence on motor learning and the consequent phenomena of neuronal plasticity. We also summarized the evidence linking physical activity to motor learning and neuronal plasticity phenomena.

Material and Method

Three electronic bibliographic databases: PubMed, Scopus and Web of Science, were searched. The searches were carried out using the set of keywords reported in Figure 1: Plasticity, Neuroplasticity, Cortical Reorganization, Motor Learning, Motor Re-learning, Sport,Physical Activity.In this figure key point is the AND block, thatconnects the other blocks, each of them is composed of several synonyms, separated by the OR condition. All not pertinent studies and those written in a language other than English were excluded.

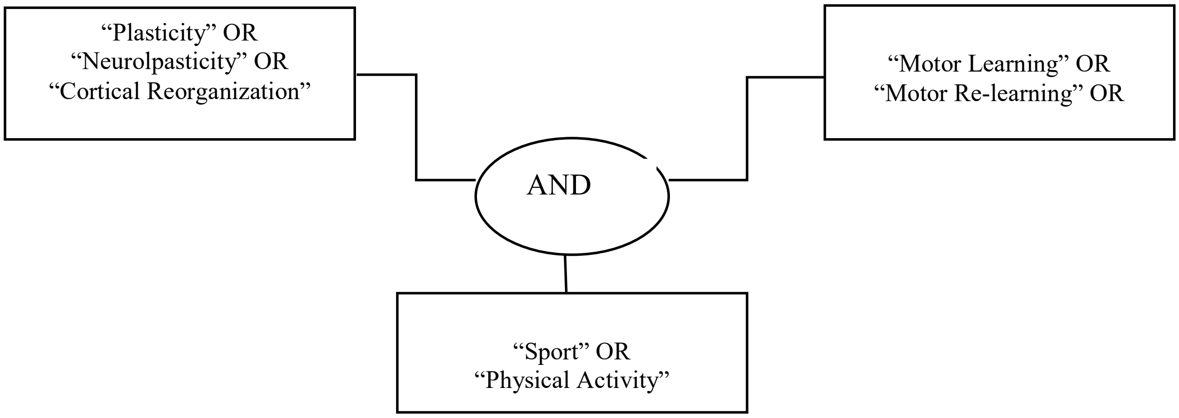

Fig 1. *Set of Keywords*

Results

As a first step, articles with the aforementioned keywords were searched. 734 articles have been found. The titles were reviewed and any titles that were not relevant were discarded. A total of Ninety-four articles met the criteria and abstracts were reviewed. Thirty-three articles have been found suitable and included in this study.

Neuroplasticity and Cortical Reorganization

The experiments of Merzenich in the monkey(Merzenich et al., 1983), on the cortical reorganization of the hand area following a surgical section of the median, date back to the first half of the 1980s. The neurons in the cortical representation area, which in normal conditions responded to the stimulation of the skin territories innervated by the median, a few days after the section, responded to the skin stimulation of the territories innervated by the radial and ulnar nerves. Subsequently, these observations were confirmed and refined with different methods in other species and in humans.

Another experimental setting was the Braille system, created by Louis Braille in the early 19th century. It consists of a set of protruding points that correspond to letters, or groups of letters, which are perceived by people with vision impairment through the fingertips, thus allowing reading. Generally, there is a high interindividual variability in the way of using the fingertips to perceive the points. In principle, Braille readers use two, sometimes three fingers (II, III and IV). It clearly follows that each Braille reader offers the possibility of verifying the effects of training on the cortical representation of the stimulated fingers, the adjacent unstimulated ones, and the contralateral ones. The Braille reading training determines a modification of the sensitive cortical representation of the stimulated and adjacent unstimulated fingers; however, concerning the counter-lateral homologous fingers of the non-reading hand, no cortical alteration is present. It has also been found that blind people who use the Braille system show an increase also in the representation of the motor cortex of the stimulated fingers and an alteration of the normal omuncular topography of the sensorimotor representation of the stimulated fingers, while no modification of the omuncular topography in non-sighted people using a single finger, or in sighted people has been showed(Hamilton & Pascual-Leone, 1998).

Therefore it is clear that cortical reorganization processes follow precise mechanisms. Plasticity does not represent an occasional condition, but a permanent state of the nervous system that allows us to activate a variety of mechanisms with the meaning of adaptive responses to environmental mutations.

However, the pathophysiological mechanisms of this recovery remain unknown. On this issue, thanks to human brain mapping methods, in recent years we have been able to enrich the knowledge that until then had been largely confined to animal models.

Motor Re-Learning

Alongside, and subsequently, to the events of cell plasticity, a set of cortical reorganization phenomena are activated with the meaning of compensation mechanisms; they represent phenomena of "learning". This last process follows a path that basically consists of two phases: in the first there is an unmasking and strengthening of existing connections, while in the second there is the creation of new connections.

From this possible pathophysiological sequence emerges a perspective of intervention offered by the modulation of the activity of the healthy hemisphere in order to increase or reduce its activity as needed. For example, Mansur et al., showed that low-frequency TMS in the unaffected hemisphere practiced 1-2 months after a stroke is able to accelerate functional recovery(Mansur et al., 2005; Montesano, Tafuri & Mazzeo, 2013; Montesano et al, 2013). According to the authors, this would be due to the inhibition of the unaffected hemisphere induced by TMS, which would thus free the one affected, by excessive transcortical inhibition. However, it must be said that another study carried out by Werhahn et al.(Werhahn et al., 2003) in similar ways did not achieve the same results. This discrepancy makes evident an extremely critical variable, which is the timing of the intervention.

The evidence regarding the ability to interfere with cortical plasticity phenomena suggests two important considerations: the first is that the cortex has a constant ability to "shape itself" in response to changes of a different nature and since learning and experience are capable to interfere with this process it is conceivable to apply strategies aimed at "forcing" these processes; the second is that cortical plasticity phenomena are constant.

Motor Learning and Sport

Motor learning is defined as the occurrence of a relatively permanent change in performance or behavioural potential achievable through direct experience or observation of others(Adams, 1971). The movement, following repetition and training, from imprecise and coarse, becomes more and more fluid, thus reaching the goal(Di Palma & Tafuri, 2016; Di Palma, Raiola & Tafuri, 2016; Raiola, Lipoma & Tafuri, 2015; Schmidt, 1975). According to Paul Fitts, in another study, the transition from a coarse movement to a precise and automated execution occurs through the succession of three phases(FITTS, 1964).The first phase of this process is called cognitive phase, in which the beginner finds himself having to understand the purposes of the action to be acquired and how to perform it. In this phase, the individual is aware and applies the rules that he begins to translate into motor acts. This phase is also called vocal, since the subject uses subvocal verbalization to repeat the movements he is making. It is characterized by poor performance and by movements that require a high-energy expenditure. The second phase is called associative because the subject begins to associate movements, making structured and finalized motor sequences. During this phase, the movement already begins to be less coarse and better controlled. The repetition of the movement learned during the associative phase involves the passage to the third phase, of automation. In fact, the third phase develops the automation of motor sequences even during complex conditions, such as during competitions. This degree of competence is achieved only with a lot of practice.

The main subcortical structures that come into play during motor learning are mainly the cerebellum and the striated nucleus. The cerebellum is more involved in the very first phase of acquisition, and thanks to its plastic effect, it changes its circuits following the repetition of certain motor patterns. The striatum subsequently proposes the correct type of strategy to be used for learning(Rossi et al., 2008).

During the last few years, thanks also to the aforementioned neuroimaging techniques; knowledge about the neural substrates of learning motor skills has increased. Several studies have analysed the plasticity processes that cause a cortical reorganization, and in particular of white and grey matter(Dayan & Cohen, 2011).

Anatomical changes may be present during the initial stages of the practice and do not take place during the subsequent stages, or, a regression may occur in the stages following the start of the practice. In this regard, Driemeyer and colleagues demonstrated in a research, an increase in gray matter in the initial stages of practice, precisely during the learning phase, without any further increase during the improvement of the learnt skill(D'Angelo & Rosa, 2020; Driemeyer et al., 2008).

Several studies in the field of neuroplasticity research provide strong evidence of a positive correlation between motor and cognitive performance and the density and volume of gray matter(Aydin et al., 2007)(Etgen et al., 2005)(Gaser & Schlaug, 2003)(Jacini et al., 2009), while only a few studies report the inverse relationship, that is, a better performance associated with lower volumes of gray matter(Maguire et al., 2000).

Several important aspects related to dance have been addressed in the literature, one of which is represented by the fact that, through structural magnetic resonance imaging, it has been seen that sensory, motor and cognitive training modulates brain morphology(Jäncke, 2009b)(May & Gaser, 2006). Studies on physiological and structural brain functioning on expert and beginner dancers have revealed substantial differences. It has been seen that the increase in speed and accuracy of the typical performance of expert dancers are associated with changes in the primary motor cortex, in the form of an increase in the number of synapses per neuron in the fifth layer of M1. The differences found between experts and beginners are unequivocally the product of training; the greatest competence is associated with increases in grey matter in some areas. This structural growth reflects an increase in cell size, the growth of new neurons or glial cells, or perhaps even an increase in the density of the spine, but seems to reverse when practice ends, although performance remains at high levels. In addition, experts compared to beginners seem to show "neural efficiency", the trend towards greater distinct neural activation. However, there is an ongoing debate on the direction of observed effects(Bengtsson et al., 2005)(Han et al., 2009)(Imfeld et al., 2009)(Jäncke, 2009a)(Schmithorst & Wilke, 2002). To date, however, there is a tendency to consider these alterations as the result of assiduous practice(Aydin et al., 2007)(Bengtsson et al., 2005)(Cannonieri et al., 2007)(Maguire et al., 2000).

In addition to plasticity in dancers, the correlations between plasticity and motor learning in other sports have also been investigated. Park et al. went to investigate this process in basketball players, confirming a variation in the volume of grey matter in different cortical and cerebellar areas(Park et al., 2009). A further study confirms this variation in golf players(Jäncke et al., 2009) compared to controls that do not practice sport. Moreover, a study of Magnetoencephalography, was able to observe neuroplasticity phenomena in people who practice meditation, compared to people who have never practiced meditation and other forms of physical activity(Lardone et al., 2018).

Discussion and Conclusions

This brief review provides a theoretical framework of the mechanisms underlying motor learning and the resulting neuronal plasticity phenomena. Particular attention has been paid to the role of physical activity, which contributes significantly to improving the state of health of the brain, inducing neuroplasticity phenomena through the learning of motor sequences. Exercise through the experience of movement would be able to create favourable conditions for an adaptation of brain structures to external stimuli. Physical activity induces psychophysical changes, such as vascular and neuronal changes that are decisive for an improvement in attention, memory and mood. The positive impact of sport on neuronal flexibility phenomena highlights the importance of these practices at all age levels both in physiological and pathological conditions, for the improvement of the quality of life.

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