Motor imagery turned out to be an innovative and valid means for motor learning and improvement of sports performance. Analyzing the instrumental and neurophysiologic investigations that confirm its existence and use in daily practice, this work leads as a reflection and a theoretical analysis on the meaning of the motor imagery as a higher cortical function. Particular attention will be paid on the role of somesthetic (consciousness of the body) and proprioceptive (stimuli within the tissues of the body) input have in the construction of the motor imagery and how this is an advantageous strategy for the central nervous system in motor learning.

**Key words:** motor imagery, motor learning, sport performance.

**Introduction**

Mental imagery is a cognitive ability defined (Jeannerod, 1994) as the general ability to represent different types of image even when the original stimulus is out of sight. Visual imagery and Motor imagery (MI) are two different expressions of mental imagery. Visual imagery is a mental imagery which includes the sense of having “images" in the mind, it is the ability to create mental representations of things, people and places absent from individual’s visual field; it is our common daily experience, when we mentally represent ourselves and “see" ourselves doing something. It is therefore easier to evoke but still recalls an external imagery since it is composed of contents that have no direct reference to information related to the soma. MI, on the other hand, has been defined as the ability of a subject to mentally represent an action without producing movement, it is therefore a dynamic state in which a subject mentally simulates a certain action (Decety, 1996; Kosslyn, 1989).

The construction of an MI refers to tactile, pressure information, etc. which allow the subject not to "see himself" but to "feel himself" performing an action (Decety, 1996; Pantè, 1997; Perfetti, 1997). In MI, therefore, the subject mentally constructs the action on the basis of the memorized and recalled somesthetic information, which he reproduces and retraces in the construction of the mental imagery. MI thus shows many similarities with the recognition scheme that Schmidt (1975) identifies as an integral part of the motor scheme together with the re-enactment scheme. However, they are two distinct learning systems that should not be confused since the first, the MI, is a motor learning tool while the second, the motor scheme, is the result, the abstract rule, the concept, the relationship arising from motor learning (Decety et al., 1989). Over the years, many scientific studies have focused on this complex but fascinating topic, which brings us closer to the world of sports training through the study of motor learning and in particular through the study of the nervous system. In fact, the positive effects of the use of MI in improving motor performance has been widely demonstrated (Guillot et al., 2010). MI is a very important area in the sciences of human movement but is still theoretically unexplored and therefore often treated with generality. Many experimental studies have used, over the years, different criteria to investigate the mental representation of motor activities. Therefore, based on the type of approach, we can categorize them into three large groups analyzed below.

**Discussion**

Motor imagery: experimental data

In the early years of interest in this topic, psychological tests and mental chronometry were very useful techniques for studies on this field. In fact, a series of experiments carried out by measuring mental chronometry on different motor tasks (Decety et al., 1989; Guillot & Collet, 2005), showed a substantial isochrony between the time actually used to perform a motor task and that used to imagine it. Mental chronometry, although not providing information on the quality of MI, is a very important tool for examining temporal organization of simulated actions. It provides information on the temporal matching between real and simulated movements, therefore involves the comparison of movement times during the simulation and execution of a motor task in various conditions (fast and slow or short or long-lasting movements). The temporal properties of the motor imageries are influenced by various factors, so much so that mental chronometry has also been used to evaluate MI capacity in clinical populations (McAvinue et al., 2008; Malouin et al., 2008; 2012).
In fact, MI timing seems to have a linear relationship both with the difficulty of the task and with the intensity of mental effort (Louis et al., 2008; Collet et al., 2011); and this could be related not only to a pathological state, which in itself makes it difficult to organize a mental representation of the movement, but also with the level of experience of the movement itself, as for example it can happen between an expert athlete and a young athlete. There is also a relationship between the chronometric data and MI speed, it has been seen that voluntary change in MI speed can have positive effects and therefore facilitate motor learning. For example, reducing the speed of the MI could slow down the actual movement and allow the athlete to make corrections and adjustments with greater ease and effectiveness (Jenny & Hall, 2009; Collet et al., 2011) but at the same time, not controlling the increased MI speed could also invalidate sports performance because speed could be confused with "haste"! (Collet et al., 2011). For these reasons, chronometric measurements are then very useful tools in the practical temporal measurement of MI, they are easy to use and cost-effective, but their interpretation is not always immediate because it is necessary to consider different aspects that can influence the MI ability of the subject (Guillot et al., 2004; Collet et al., 2011).

Motor imagery: analogies of the effects on the vegetative system

The imagined movement causes visceral responses such as increased heart rate and pulmonary ventilation (Harris & Robinson, 1986; Jowdy & Harris, 1990; Decety et al., 1991) similar to those produced by actual execution. A recent experimental study has demonstrated a direct cross-talk between cardiovascular control and proprioceptive representation of movement (Sebastiani et al., 2019). Of particular interest is the fact that vegetative activation during MI increases beyond the level of the real metabolic demand, and this could mean that this system has a central origin, the structures assigned to central motor programming would anticipate the need for energy mobilization required by the planned movement, in the same measure in which they anticipate the amount of activity necessary to produce the movement itself (Decety et al., 1993). This is certainly consistent with the current idea on the functioning of the Autonomous Nervous System that is directly involved also in cognitive functions, such as MI. Both become tools for interacting with the environment and represent potential operations that facilitate the mental construction of motor action’s planning (Collet et al., 2013).

Motor Imagery: neuroimaging studies

Over the years, neuroimaging methods (measurement of regional cerebral blood flow (rCBF), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), transcranial magnetic stimulation (TMS), have provided convergent evidence that both imagined and performed movements share the same neural substrate of the movement performed. In particular, the data obtained from this type of measurements show that during the MI evocation there is the activation of cortical areas that change depending on the task required. These studies demonstrate both the existence of MI and the fact that the activation of the cortical areas is not connected to muscle contraction but to the nature of the task and the motor programming process (Decety et al., 1994; Jeannerod, 1994). Ingvar & Philipson (1977) open this line of research requiring some subjects to perform or imagine hand movements.

In both cases, the frontal lobe is activated while area 4 (primary motor area) is activated only during the actual execution. Decety et al. (1988) confirms these data, requiring right-handed subjects to write numbers and letters and other right-handers to imagine doing the same task. In both cases the rCBF increases from 10% to 25%. During the task the Rolandic areas are mainly activated, while during MI there are increases in the prefrontal and premotor flow.

Other studies show a partial activation also of the primary motor area in MI tasks. Porro et al. (1996), examining the movements of the fingers and their mental representation in 14 right-handed subjects, demonstrate common activations within the pre-rolandic cortical areas. The evocation of mental images therefore determines changes in brain flow detecting an activation of brain areas superimposable to those active during real movement, even in the presence of a diversification determined by the nature of the task (Decety et al., 1997). Many studies carried out with the fMRI show that, in the same imagined gesture, MI evocation activates the same areas as the perform phase, i.e. the supplementary motor area, the premotor area, the primary motor area, the cerebellum, the basal ganglia (Lotze & Halsband, 2006; Munzert et al., 2008; Guillot et al., 2009; Mizuguchi et al., 2012).

Cognitive function of Motor Imagery

The cognitive function of MI facilitates the learning of motor skills but it must be a complement to the complex sports training process and not its substitute (Driskell et al., 1994; Guillot & Collet, 2008). If we return to the initial definition of MI given by Decety (1996; 1997), the most important point is that, according to this author, the Central Nervous System (CNS) would use MI to simulate an action.

In other words, the brain would have had an ability, then maintained during evolution, since in some situations it is biologically more useful to simulate an action before carrying it out, even just for the need not to perform acts without predicting the final outcome. MI gives the possibility of simulating a sequence of actions even when the CNS does not have all the knowledge necessary to predict the final outcome of what has been programmed, thus representing a learning tool (Kosslyn, 1989;
Berthoz, A. (1996; Pantè, 1997). In fact, while during the execution of a learned motor activity the nervous system can adopt an energy saving strategy - using the attentional mechanisms just for the final verification of the act - in the motor activity during the learning phase it is necessary to address attentional mechanisms throughout the sequence, before predicting the final outcome. Being able to evaluate this task through a simulation represents an obvious biological advantage. This creates a learning mode for simulation different from that used for trial and error, in which the central element would be MI, that is, the ability to simulate actions (Berthoz, 1996; Reggiani, 1999).

For the purposes of identifying the neuropsychological mechanisms underlying this process, the definition given by Farah (1984) is illuminating. The image is a transitory representation in short-term memory, based on information stored in long-term memory. The evocation of an image takes place, therefore, by using data stored in previous experiences, recalled in the short-term memory after possibly integrating them with perceptual data obtainable from the current situation.

For the purposes of motor learning, it is very interesting what Berthoz (1996) hypothesized; he believes that the CNS, faced with the need to organize a motor task, has two programming possibilities (Reggiani, 1999), the first one, defined as conservative, which consists in the implementation of movement patterns already tested and stored, which can be modified in some parameters such as speed, intensity and amplitude; the other one, defined as projective, based on the ability to simulate the action without performing it.

This second possibility would identify an alternative learning method allowing us to learn without doing, replacing the trial and error mode. This hypothesis could confirm that the fundamental function of the use of MI by the CNS could be the simulation of solutions of motor tasks in the learning phase.

Conclusion

Finally, MI should be understood as a multisensory process that involves not visual but kinesthetic, tactile and in some cases, vestibular and auditory perceptions. In this process, the visual imagery is only the first link facilitating the triggering of MI. MI is the only one that can promote the “internal” repetition of the gesture in which the somesthetic sensory components are activated. These somesthetic sensory components determine the overlapping of the cortical areas activated in the real and mental execution of the action. Through internal representation, the subject can (Murphy & Jowdy, 1992), anticipate problems; define the spatial and temporal characteristics of the action; define the targets; define effective execution strategies. Therefore, the MI can be considered as a valid tool to promote motor learning in all its phases as well as in the learning and improvement of the sports gesture and, therefore, in the improvement of sports performances (Driskell et al., 1994; Olsson et al., 2008; Mizuguchi et al., 2012). Many studies show the increase of sports performances by the use of MI both for an improvement of basic skills, such as strength and flexibility (Veerger & Roberts, 2006; Mizuguchi et al., 2012), and of a greater detail in the execution of the sports gesture (White & Hardy, 1998; Olsson et al., 2008; Munzert et al., 2008; Mizuguchi et al., 2012). It is also significant that high-level athletes have greater ability and precision in evoking MI (White & Hardy, 1998; Munzert et al., 2008).

So, in light of what is known today and of the modern functional investigation technologies, it is clear that the next step for understanding the relationship between imagery and action is to understand to what extent the MI can influence physical training and vice versa. That is, if we can imagine a motor action that we do not know how to be performed physically and therefore make the brain believe that we are actually performing it (Olsson & Nyberg, 2010). Further studies should clarify this hypothesis and guide us in the structuring of specific training programs.

References


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