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Postural Control Modulation During Motor Imagery Tasks: A Systematic Review

REVIEW

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Abstract

The motor imagery (MI) has two strategies (kinesthetic and visual) and can be defined as an act to codify the mental rehearsal of an intended action, without executing it. Studying the execution of the movement, several researchers believe that the deep muscles of the trunk are activated before the agonist of the limbs, showing a motor neurophysiologic recruitment order. This behavior can be also seen during MI tasks as the postural control, because the postural control is inserted in the movement context. The aim was to investigate, by a systematic review, evidences of MI and the postural control on healthy subjects. The selected articles were searched on different databases, dated from 1985 to 2014. Twelve studies were selected regarding the MI and the postural control on healthy subjects. All articles using balance scale or those which were about clinical conditions were excluded. Data show that kinesthetic MI with high levels of vividness promotes major changes in the body oscillations when comparing with the visual MI. To date, the number of articles about this theme is limited and the results should be interpreted cautiously.

Keywords
Postural control; postural balance; motor imagery; mental simulation; mental training

Introduction

The motor imagery (MI) can be defined as the act to codify the mental rehearsal of an intended action, without executing it [1]. The MI has two strategies: (1) kinesthetic (first person), which the individual feels himself executing the movement and (2) visual (third person), which the individual sees the movement performed by himself or another person [2]. The imagination and the feeling of a movement are phenomenona specifically related, and they have a voluntary control profile [3]. This conscious action can bring non conscious neurophysiologic changes and also induce events through the autonomic nervous system (ANS) [4]. Different methodologies have shown the relevance of MI through human body. These findings reassure that there are common neural mechanisms between MI and the movement execution (ME) [5], that can modify the electroencephalographic (EEG) signal during the mental effort tasks [6], and also induce changes on cardio-respiratory activities in the same conditions [7-12].

Several studies in neuroscience have evidenced the benefits of MI and propose their use in improving performance or functional recovery in different conditions: sports practice [13-14]; geriatric [15]; amputation [16]; gait disorder [17-20]; neurological disorder [21-25] and orthopedic disorder, including the postural control [26-28]. The postural control system depends on three functional components: (1) biomechanics, involving muscular and join extensibility, as well as the range of motion of each body segment; (2) motor skills, which involves the strategies of response to the anteroposterior body sway (ankle and knee strategy) and external interferences (hip strategy) [29-32] and (3) sensorial system (visual, vestibular and proprioceptive), responsible for the control of postural balance [33-34].

Traditionally, it was believed that only the basal ganglia, cerebellum and spinal cord regulated the postural control [35] and historically, that this type of control was basically an automated sensorio-motor task [30, 36-37]. However, it was observed that both animals and humans with cortical injury (with cerebellum and brainstem preserved) showed an abnormal postural control [38], supporting the hypothesis that the cerebral cortex could interfere in the adjustment of postural balance in voluntary responses [39]. Furthermore, the motor system is involved not only in producing the movement, but also in its representational aspects, such as recognition and action learning through observation and mental simulation [40]. Part of the neuronal mechanisms involved in the movement planning is also recruited during the mental simulation state designated as "S-state". Those "S-states" are related to situation which anticipates the action, manipulating neuronal networks that codify the intended action, without the execution [4-5].

In this context, the voluntary movement could be linked to the postural control. Therefore, it could be expected that the simulation of a movement during a MI task could activate part of the circuit and induce a postural adjustment. Investigations involving the MI and postural control are very recent [41-49] and have been speculated that the MI blocks the ME in different brain levels, although those mechanisms are yet not well understood (for review see references [5] and [40]). The objective of this study was to investigate, through a systematic review, the evidence of correlation between the MI and the postural control in healthy subjects.

Methodos

The present study is characterized by a systematic literature review, which aims to gather, critically evaluate and conduct a synthesis of scientific evidence [50].

2.1 Data's source

On this systematic review, two books were used, one about the "Global Postural Reprogramming" [35] and the other about "The Neurophysiological Foundations of Mental and Motor Imagery" [4]. Those books are extremely relevant to this specific area of knowledge. For this specific subject, articles published on the following databases were selected: Pub med/Medline; Scholar Google; PEDro and Scielo, using motor imagery, postural control and mental training combined or not either in English as key-words, the articles are dated from 1985 to 2014 (see **table 1**). They were used on the theoretical substantiation and discussion different articles in a larger period (1910 – 2014), which the more parcel of information were from the past 10 years. 49 references were referent to the last 10 years (2005-2015) and all the others (51 references) have more than 10 years or more of publication (≤ 2005).

2.2 Types of study

Studies about the randomized and controlled clinical rehearsal, as well as the observational studies of the transversal type were selected. They explore the evidences on the correlation between the MI (or mental training) over the balance control in healthy people using the force platform as an instrument to quantify the Center of Pressure (CoP).

2.3 Participants, intervention and exclusion criteria

Studies that analyzed healthy people with no neurologic and/or orthopedic injuries which could implicate the balance were included. In these studies, the MI or mental practice should be accomplished and also analyze the postural balance control through force platform, since this is a reproductive method [51], reliable [52-54] and validated [55]. 24 references were eliminated that used only the scale to measure the balance or mentioned clinical conditions (Stroke and Parkinson disease). On all articles about the subject, only one used oscilloscope to evaluate balance control [26], the remnant of the articles used force platform on healthy subject.

Results

In total, twelve references were selected about the MI and the postural control, from 1985 to 2014. In the **table 1** summarizes the results of the articles research at the databases, and also the articles level of evidence of the articles and its impact factor in each journal. **Table 2** summarizes the studies about the randomized and controlled clinical rehearsal; finally, **table 3** referrers to the observational studies from the transversal type.

Table 1. Research results at the databases.

Database	Articles Found	Selected	Author and Year	Level of evidence	Journal's impact factor in 2013
Pub med/ Medline	24	7	Imbiriba et al., 2006 [43]		
			Rodrigues et al., 2010 [41]		2.026
			Grangeon, Guillot & Collet, 2011 [44]		3.122
			Heurley et al., 2013 [46]		1.536
			Kawasaki & Higuchi, 2013 [47]		1.393
			Boulton & Mitra, 2013 [45]		1.060
			Lemos, Rodrigues & Vargas, 2014 [49]		3.301
PEDro	8	2	Hamel & Lajoie, 2005 [28]	2/10	1.006
			Fansler, Poff & Shepard, 1985 [26]	5/10	3.360
SciELO	1	1	Rodrigues et al., 2003 [42]		1.856
Scholar Google	3	2	Choi et al., 2010 [27]		0.180
			Lemos et al., 2014 [48]		2.906

Table 2. Studies trial clinical randomized and controlled.

Author and Year	Sample	Intervention	Methodology	Results and Conclusions
Fansler, Poff & Shepard, (1985) [26]	n=36 (women over 70 years), n= 12 for each group	**Group A:** attention and participation tasks **Group B:** relaxing instructions **Group C:** MP and physical practice the balance control in one leg 3 groups realized the tasks for 3 following days	Oscilloscope	The MP associated with physical practice can improve the balance control in one leg
Hamel & Lajoie, (2005) [28]	n= 20 (aged 65 to 90 years old) n=12 (experimental group) n=8 (control group)	**Experimental group:** After listen signal, the participants should performed the MP maintaining a straight and stable standing position once a day (dual-task), in six consecutive weeks. **Control group:** Did not receive any MP training Both groups performed five minutes of relaxation	Force platform (50Hz), Berg balance scale and KMI e VMI survey (KVIQ)	The PM showed significantly reduced the reaction time demand attention in dual-task and the oscillation in the AP directions of CoP when compared with the control group
Choi et al., (2010) [27]	n=21 (7 men and 14 women healthy, aged to 20 years old), n= 7 for each group	**Physical Practice (PP) Group*:** Received the balance treatment together to the visual feedback of the CoP **MP Group*:** performed the MP of the same training received at FP * Both groups accomplished 30 minutes of MP, in 5 days for 3 consecutive weeks **Control Group (CG):** This group did not accomplish any kind of training	Force platform (50H) and feedback visual training equipment	The FP group showed improvement compared with MP and CG. The PM group showed an improvement when compared with the CG. The authors concluded that the MP in postural balance disorders can be effective

Legend: s=seconds; MI= motor imagery; KMI= kinesthetic motor imagery; VMI= visual motor imagery; AP= Anteroposterior (Y-axis); ML= Mediolateral (X-axis); CoP = center of pressure; CoG= center of gravity; EMGS = surface electromyography.

Table 3. Observational studies of the transversal type.

Author and Year	Sample	Intervention	Methodology	Results / conclusions
Rodrigues et al., (2003) [42]	n=49 (23 male sand 26 females healthy with aged to 23 years old)	**Tasks:** a) remain standing during 20s; b) count mentally from 1 to 15; c) imagine themselves executing a rising on tiptoes 15 times and d) execute the same movement 15 times. The groups were separated according to the strategy adopted (VMI or KMI)	Mental chronometry and force platform (50Hz). The EMGS register was not carried out	The mental chronometry did not show any difference. A significant increase in the displacement of the CoP in the AP direction in participants found made use of kinesthetic strategy, with no significant changes in the oscillations of the CoP in the group using the visual strategy

Imbiriba et al., (2006) [43]	n=12 (Participants aged 26 years old and had some type of blindness)	Similar protocol l used by Rodrigues et al. (2003), though the VMI tasks were not accomplished, due to the patient's blindness	Force platform (50Hz) and EMGS lateral gastrocnemius	The mental simulation task, being absent for resting, counting and executing. The KMI is strongly associates with somatic and autonomic changes
Rodrigues et al., (2010) [41]	n=18 (8 males and 10 females healthy with aged 19 to 33 years old)	**Tasks:** a) to execute rising on tiptoes; b) to perform VMI and KMI of the same movement and c) to imagine themselves singing a song (mental control)	Force platform (50Hz) and EMGS lateral gastrocnemius	A significant increase in the displacement and mean velocity of CoP in the AP direction in trembling component during the task of KMI, when compared with the tasks VMI and control
Grangeon, Guillot & Collet, (2011) [44]	n=20 (healthy males aged 19 to 34 years old)	The participants executed and imagery three tasks with their eyes closed: 1) to remain standing; 2) to counter- movement jump and 3)finger-to-thumb opposition	Force platform (500Hz)	A greater variability of body sway of the CoP in the AP and ML directions during KMI of opposition and jump tasks, when compared with the VMI
Heurley et al., (2013) [46]	n=20 (healthy students with aged 20 to 24 years old)	The participants had to read short sentences while execute / imagery a situation stable and instable (unipodal stance)	Force platform (100Hz)	The result showed that a instable situation decrease the velocity of CoP, when compared with stable situation
Kawasaki & Higuchi, (2013) [47]	n=16 (7 males and 9 females healthy with aged 22 to 25 years old)	The participants has that performed mental rotation of a foot (experiment 1) view the foot stimuli (experiment 2) on unipodal and bipodal stance	Force platform (50Hz)	The postural velocity of sway for unipodal standing, but not for bipedal standing, were decreased immediately after the foot stimuli, suggesting a immediate postural stability
Boulton & Mitra, (2013) [45]	n=48 (23 males and 25 female healthy with aged 18 to 21 years old)	The participants imagined reaching movements with the feet closed or semi-tandem Romberg stance	Force platform (60Hz)	The result showed reduction in head/trunk sway during motor imagery arm movement in relation to quiet standing
Lemos et al., (2014) [48]	n=23 (11 males and 12 females healthy with aged 20 to 38 years old)	The participants imagined three movements using the KMI: (1) rising on tiptoes; functional reach (2) forward and (3) lateral direction. After each task, the subjects reported the level of imagery vividness and were grouped into a high and low group	Force platform (50Hz) and EMGS of the muscles lateral gastrocnemius and deltoid (medial and anterior)	The high group present changes in CoG variability in the AP direction during KMI of rising on tiptoes. However, the CoG variability in the ML direction was higher during KMI of rising on tiptoes and lateral reaching
Lemos, Rodrigues & Vargas, (2014) [49]	n=12 (5 females and 7 males healthy with aged 20 to 33 years old)	Tasks: to perform VMI (1) and KMI (2) rising on tiptoes and (3) imagine singing a song (control task)	Force platform (50Hz) and EMGS of the muscles lateral gastrocnemius	The KMI promotes a major CoP displacement than VMI and control imagery, with stronger EMGS-CoP temporal association during KMI, suggesting an effect on muscle activity and postural sway

Legend: s=seconds; MI= motor imagery; KMI= kinesthetic motor imagery; VMI= visual motor imagery; AP= Anteroposterior (Y-axis); ML= Mediolateral (X-axis); CoP = center of pressure; CoG= center of gravity; EMGS = surface electromyography.

Similarities between of movement execution and motor imagery and its repercussions on postural control

Different factors may determine the ability of an individual mentally simulate different movements, such as age [56-57], gender [58], the difficulty of the task [59] and fitness level (skill/motor experience) that the participant presents to the designated task [13].

Some properties observed during the ME are also present during the MI, as their temporal regulation and its biomechanical aspects [1, 3, 8, 60-62], suggesting that there are similarities in the mental states during the execution and imagination of the same task [1, 62-63]. With advances in neuroimaging techniques, this proposal was confirmed, demonstrating the existence of overlap between the neural circuits during the execution and imagination of the same task [64-65]. The circuitry involved in both the execution and the simulation of a task include: supplementary motor area; primary motor cortex; parietal cortex; basal ganglia and cerebellum [5, 64-70]. Therefore, the motor system is not only involved in the production of voluntary movement, but also in their representational aspects which are accessed during the MI [1, 8, 63].

In the context of postural control, the voluntary movement is accompanied and preceded by anticipatory postural phenomenon [71-72], because postural control is inserted in the context of the movement [73-76]. In studying physiological movement, several researchers showed that the deep muscles of the trunk (antigravity) are activated 50 milliseconds (ms) before the muscle agonist of the movement, both in the lower limb [73-74] as in the upper limb [75]. The evidences indicate that there's a motor recruiting order, in which the deeper muscles of the trunk (antigravity) work in anticipation to the movement from the limbs, in response to the loads imposed by them, to maintain the postural adjustment and the trunk stability during the ME [73-76]. In this context, it could be expected that the MI as a physiological movement (different tasks) would recreate the same effect under the control of the postural balance.

Studies suggest that kinesthetic MI has a network specific sensorimotor that facilitates the corticospinal modulation with more range than the visual MI [2, 65]. There are speculations that the visual MI occurs through a distinct, related network of mirror neurons (parietal-frontal), which when activated by the observation of an action, allows the meaning of the action automatically, transforming the image stored in the memory in a mental observation of action (third person) [4]. Thus, both the visual strategy of MI as kinesthetic MI has a distinct mental construction [2, 65] and therefore it could be expected that their repercussions on the postural control also behave distinctly, as will be detailed the follow.

Effect of kinesthetic motor imagery on postural control

Modulations on postural control can be induced by MI. Imbiriba et al (2006) [43] evaluated blind subject having etiological differences. This result suggests that the primary motor representation of the individual who has impaired vision depends on the proprioceptive kinesthetic information [43]. The majority of the results in the present study (see table 3) show that the kinesthetic MI in different type of tasks promotes major changes in postural sway [41-43, 44] and/or EMGS activity [49] when compared with the visual modality. A recent study has shown that kinesthetic MI can modulate the postural control. However, this influence occurs only in participants with high levels of vividness of the imagined movement [48], which has been correlated with increased excitability of the motor cortex [77] and changes in spinal-reflex [78] during the MI. Furthermore, the use of MI as a mental practice (daily training) in clinical rehearsal (see **table 2**) can improve the balance postural in one leg [26, 46-47] or two leg support [27-28], decrease the oscillation in the AP direction, due to the reduction on the reaction time of the postural control [28].

Some these evidences, together, indicate that kinesthetic MI can modulate the postural control depending on the imagined direction of motion. The task of kinesthetic MI of jump can increase the variability of sway in CoP in the vertical direction (Z-axis) (for review see reference [44]). Tasks kinesthetic MI of rising on tiptoes can increase the sway in CoP in anteroposterior direction (Y-axis) [41-42, 48]. The task of the functional reach in the lateral direction (lateral reach) shows an increase in the CoG variability in the mediolateral direction (X-axis) [48]. These studies suggest that the postural response during the MI presents similarities with the task in each direction (Y, X and Z-axis), indicating the existence of specificity directional of the imagined movement (task-dependent).

Several neural mechanisms are responsible for preparation and programming of the movement, with minimal or none efferent motor activity [1]. Therefore, the MI activates not only the motor command (frontal cortex), but also activates the feedback kinesthetic representation (parietal cortex), from sensorial inputs (proprioceptive and exteroceptive) connecting anatomically to the primary motor cortex (cM1) by U fibers (for review see reference [4]). The kinesthetic MI specifically extracts a subconscious activity of the muscles of the mental representation, requiring a proprioceptive ability of perception of the imagined movement (kinesthetic memory) [79]. This ability, integrates proprioceptive information from muscles, tendons and joints in the body position and imagined movement [44], activating specifically somatomotor areas [2, 65], and it can modulate the muscle activity associated with changes in CoP [49].

Motor inhibition during the mental simulation of tasks

A recent review study emphasized three possibilities to inhibit the motor command during the MI: (1) parietal cortex (motor inhibition during the mental representation construction process; (2) frontal cortex (suppressive influences by the cortex in areas designated to formulate the motor command and (3) inhibition influences by the cerebellum and spinal cord. Particularly when a program of movement is not well adapted and changes are required in one or more parameters of directions or even in the range of motion, the full inhibition of the movement is not necessary, but only to adaptation the program to the individual. This flexibility on the mechanism of central inhibition may result in the interaction between the inferior frontal gyrus with the basal ganglia, responsible for programing a motor planning, which could be inhibit (for review see reference [40]).

Depending on the orientation of the movement, a systematic sequence of neuronal activation occurs before the movement begins. EEG registers show that a negative increase of the potential (between 1 and 2 seconds) happens before the ME, reflecting in a preparation of the motor process (pre-motor potential) [80]. The negative premotor potential happens fast (500ms) before the movement begins and reflects the depolarization of the dendrite network, indicating a preparatory generation of the underlying state of the cortical sensorimotor layer [81]. Studies using functional magnetic resonance imaging (fMRI) suggest that the pre-motor process may be linked to the supplementary motor area (SMA) and the reticular formation nuclei on brainstem [82], probably composing the corticospinal tract that activates the alpha motor neuron of anti-gravitational muscles (stabilizer) [35]. Studies on movement simulation show the connectivity between SMA and cM1 suggesting that SMA inhibits cM1 activity during MI spelling gamma-Aminobutyric Acid (GABA) liberation indicating an important feedback circuit of primary motor cortex (cM1) with SMA at the preparation and ME, as well as in MI [4, 82-83].

In this context, studies have shown the participation of both cM1 and SMA not only on simulation, but also on ME, as it seems that the neurons do not codify only the ME, but they are also related to the movement complexity and its learning [77, 82, 84]. Furthermore, MI and ME have showed an effective similarity of corticospinal and intracortical excitability [85]. It seems that a facilitation on corticospinal excitability occurs (SMA) during kinesthetic MI associated to the intracortical inhibition (cM1, cerebellum, brainstem and spinal cord) of pre-synaptic fiber of alpha motor neuron (type Ia), by GABA liberation, leading to volitional muscle relaxation, preventing ME [83, 86]. However, this mechanism is still unknown, and lots of hypothesis have emerged about the nearest anatomic areas (SMA and cM1) [82], suggesting that the inhibition of cM1 (pyramidal tracts) during the MI happens on the motor planning stages [40, 87], leading to changes in postural control (functional reach test), regardless of age [88].

Another question, in the same context, is that unconscious muscle activity seems to be specific to the type of muscle contraction (concentric or eccentric) during an MI task [89]. Data shows that there’s incomplete inhibition of motor command specifically during kinesthetic MI tasks [19,83,90], which seems to evoke motor representations involved in balance control, through SMA and cM1 activities modifications [85]. Recently it has been speculated that there may be an integration between slow muscle activity (stabilizer) and fast (mobilizing) during MI [44], just as there is on ME [73-76]. Based on this discussion, it can be suggested that using the kinesthetic MI strategy of imagining a task, a cM1 block happens (corticospinal tract) through SMA inhibition activity, which activates the reticuloespinal tract (by SMA activity), promoting changes on anticipatory postural displacement to the imagined movement, which is inhibited or shows minimum activity (feedforward of imagined movement).

Record of the electromyographic signal during tasks of kinesthetic motor imagery involving changes on postural control

The electromyography (EMGS) includes examining electrical potentials (membrane potential) and consists in the noninvasive assessment of the muscle activity [91]. The EMGS activity during the MI has been widely discussed [92]. Several studies show changes in EMGS during the MI in different tasks, and this difference was considered a small activity when compared to the amplitude of the signal collected during execution of the movement [89, 93-94]. However, other studies have not observed any change in EMGS during the MI [95-97].

Traditionally, experiments in MI and postural control with records from EMGS have used surface electrodes. The antigravity muscles are rich in spindles [98] and kinesthetic MI can induce an increase in the excitability of these spindles [99] and may thus facilitate the antigravity postural adjustment (change in CoP) during mental rehearsal of a task [41-42, 44, 48]. A recent study has shown that kinesthetic MI can promote a major CoP displacement with stronger EMGS-CoP temporal association (lateral gastrocnemius) [49]. However, especially small muscle activities or deeper muscles activities (antigravity or stabilizers) during the kinesthetic MI can not be registered by EMGS. Because of that, the methods used in EMGS have shown flaws in its reproducibility and reliability, as well as lack of precision in some experimental designs, making them insufficient to validate the interpretation of a data (for review see reference [4]).

The skeletal-muscles have several physiological characteristics and are activated in different frequencies, such as the slow-twitch fibers (type I) activated in low frequencies (5 to 20Hz) and fast-twitch fibers (type II) activated in higher frequencies (30 to 100Hz) (for review see reference [100]). The intensity of mental effort could create different effects in both fast and slow muscle fibers, because its EMGS records must respect the respective physiological frequency range. So it could be necessary to take notes of the records on muscle activation (surface and deep muscles) and its absence/presence during MI can be essential to control futures experimental rehearsals involving MI and postural control.

Final Considerations

According to the analyzed literature, the kinesthetic MI has shown more influence over the postural control comparing to the visual modality. However, this influence occurs only in participants with high levels of vividness of the imagined movement. The number of studies at the present moment is limited and the results should be interpreted cautiously, because there may be methodological failures that could occult registers of postural activities during the MI. Thus, more studies need to be performed to answer these and other questions in order to improve techniques for rehabilitation in orthopedic and/or neurological disorders of the postural control.

Competing interests

The authors declare that they have no competing interests.

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Authors' contribution

NSS and ACGM participated in the acquisition of data. All authors participated in the revision of the manuscript. DM, VHBH, MO, BV, PR, ST and OAC guided the design and organization of the study. NSS, ACGM and KSC drafted the manuscript. All authors read and gave final approval for the version submitted for publication.

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