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KINESTHETIC MOTOR IMAGERY MODULATES BODY SWAY

E. C. RODRIGUES,[a,b1] T. LEMOS,[a,c1] B. GOUVEA,[a] E. VOLCHAN,[a] L. A. IMBIRIBA[c] AND C. D. VARGAS[a]*

[a]*Laboratório de Neurobiologia II, Instituto de Biofísica Carlos Chagas Filho, CCS, UFRJ, Cidade Universitária 21949-900, Rio de Janeiro, Brazil*

[b]*Centro Universitário Augusto Motta (UNISUAM), Rio de Janeiro, Brazil*

[c]*Núcleo de Estudos do Movimento Humano (NEMoH), Escola de Educação Física e Desportos, UFRJ, Rio de Janeiro, Brazil*

Abstract—The aim of this study was to investigate the effect of imagining an action implicating the body axis in the kinesthetic and visual motor imagery modalities upon the balance control system. Body sway analysis (measurement of center of pressure, CoP) together with electromyography (EMG) recording and verbal evaluation of imagery abilities were obtained from subjects during four tasks, performed in the upright position: to execute bilateral plantar flexions; to imagine themselves executing bilateral plantar flexions (kinesthetic modality); to imagine someone else executing the same movement (visual modality), and to imagine themselves singing a song (as a control imagery task). Body sway analysis revealed that kinesthetic imagery leads to a general increase in CoP oscillation, as reflected by an enhanced area of displacement. This effect was also verified for the CoP standard deviation in the medial–lateral direction. An increase in the trembling displacement (equivalent to center of pressure minus center of gravity) restricted to the anterior–posterior direction was also observed to occur during kinesthetic imagery. The visual imagery task did not differ from the control (sing) task for any of the analyzed parameters. No difference in the subjects' ability to perform the imagery tasks was found. No modulation of EMG data were observed across imagery tasks, indicating that there was no actual execution during motor imagination. These results suggest that motor imagery performed in the kinesthetic modality evokes motor representations involved in balance control.

Key words: posturography, motor simulation, human balance, rambling, trembling.

It is now generally accepted that motor imagery—the mental rehearsal of given movement—shares the same neural mechanisms that are also responsible for the preparation and programming of actual movements, with minimal or no activation of the motor output (Jeannerod, 1994). For instance, the time course of a mentally simulated movement correlates with its actual execution (Decety et al., 1989; Sirigu et al., 1996), and autonomic responses are modulated likewise during both motor imagery and movement execution (Decety et al., 1991; Guillot et al., 2005; but see Demougeot et al., 2009). Moreover, there is evidence that mental practice improves motor skill learning, a phenomenon attributed to the central reorganization of motor programs (Yue and Cole, 1992; Gentili et al., 2006; Allami et al., 2008).

Motor imagery commonly involves a blend of kinesthetic and visual forms of movement imagination (Dechent et al., 2004). Volunteers can be instructed to either "feel" or "see" themselves/another person performing the movement (first or third person perspectives, respectively). Whereas the first case (internal or kinesthetic imagery) would mostly imply sensorimotor networks, in the second case (external or visual imagery) the simulation would mostly rely on the visual features of the movement (Sirigu and Duhamel, 2001). Indeed, experiments using brain imaging techniques as well as transcranial magnetic stimulation (TMS) have confirmed this proposal, showing that during the mental simulation of hand movements the recruitment of primary motor cortex and related sensorimotor areas is most salient in the kinesthetic/first person modality (Deiber et al., 1998; Ruby and Decety, 2001; Solodkin et al., 2004; Stinear et al., 2006; Guillot et al., 2008; but see Fourkas et al., 2006).

Most studies about motor imagery have relied on upper arm or hand movements. Recently motor imagery has been also employed to identify the neural circuitry of gait control with different levels of postural demands (Malouin et al., 2003; Bakker et al., 2008). However, little is known if and how motor imagery affects the postural control system in itself. Standing straight and being able to perform appropriate postural adjustments is crucial for the execution of many daily life activities. To achieve this level of control, human postural systems rely on multiple sensorimotor processes (Peterka, 2002; Horak, 2006). Postural steadiness is most often characterized by the displacement of the center of pressure (CoP), as measured with a force platform (Prieto et al., 1996). CoP displacement provides a complex output signal of the postural control system in which various cognitive, perceptual, and emotional processes are reflected (Lajoie et al., 1993; Azevedo et al., 2005; Facchinetti et al., 2006; Donker et al., 2007).

In one of the first studies dealing with motor imagery and postural control, Rodrigues et al. (2003) asked the subjects to imagine a bilateral plantar flexion movement. They observed that CoP displacements were greater for the subjects that reported to have adopted a kinesthetic as

[1] Both authors contributed equally to this work.

*Corresponding author. Tel: +55-21-25626556; fax: +55-21-22808193.
E-mail address: cdvargas@biof.ufrj.br (C. D. Vargas).

Abbreviations: AP, anterior–posterior direction of body sway; CoG, center of gravity; CoP, center of pressure; CoP−CoG, center of pressure minus center of gravity; EMG, electromyography; H-reflex, Hoffman reflex; ML, medial–lateral direction of body sway; M1, primary motor cortex; RMS, root mean square value; TMS, transcranial magnetic stimulation; T-reflex, tendinous reflex.

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compared to the visual modality of imagery. Hamel and Lajoie (2005) measured CoP displacement responses in aging subjects after 6 weeks of imagining maintaining a straight and stable standing position on a force platform. The main finding was that imagery training reduces CoP oscillation in the anterior–posterior direction. Although precluding any final conclusion, taken together these results were indicative of a postural modulation induced by motor imagery. In another line of evidence, Imbiriba et al. (2006) tested early and late blind subjects in a bilateral plantar flexion imagery task and found that posturographic parameters collected during motor imagery provide good discrimination of blindness onset.

It could be hypothesized that motor imagery modulates postural control trough the evocation of internal models. Forward internal models are implemented both during the action execution (Miall and Wolpert, 1996; Desmurget and Grafton, 2000) and the motor imagery of a given movement (Davidson and Wolpert, 2005; Jeannerod, 2006). An internal model hypothesis of postural control assumes that the state of the center of gravity (its position and velocity) are estimated by the CNS trough the integration of visual, vestibular and somatosensory systems trough a predictive, forward internal model, and that this estimate is used to adjust stance posture (Morasso et al., 1999; Kuo, 2005).

In the present study we investigated the effect of modality to perform a movement imagery task upon the balance control system. To achieve this goal, body sway data were obtained in the upright position during the execution and the imagery of a bilateral plantar flexion task in kinesthetic and visual modalities. We hypothesized that the imagery of a whole body movement, once evoking internal motor representations related to this task would increase body sway displacement, mainly in the anterior–posterior direction of oscillation, related to the chosen task. Furthermore, as kinesthetic imagery involves a higher activation of sensorimotor circuits, we expected that balance modulation would occur mostly for this modality.

EXPERIMENTAL PROCEDURES

Participants

Eighteen subjects (eight males, 19–33 years old, 156–189 cm height and 44–95 kg; range) participated in this study. Volunteers were undergraduate students with no reported neurological or orthopedic diseases that could compromise stance ability. They did not receive any previous training on motor imagery and were naive with respect to the aim of the study. The subjects' imagery abilities were classified as good, following the revised Motor Imagery Questionnaire (Hall and Martin, 1997), with a median score of 24 both for kinesthetic and visual modalities (maximum test score=28). A written informed consent was obtained and the study was approved by the local Institutional Review Board and Ethics Committee.

Experimental protocol

During the experimental session participants were requested to stand up barefoot with feet together on a force platform, with arms relaxed along the trunk and the eyes closed. They were instructed not to move their arms and head, and since their eyes remained closed during the entire experiment, no gaze orientation was given. Four tasks were performed: execute bilateral plantar flexion movements (instruction: "please rise repeatedly on your tiptoes"; name herein as execution); imagine themselves executing bilateral plantar flexions (instruction: "feel yourself repeatedly doing the same movement"; kinesthetic modality); imagine someone else performing the same movement (instruction: "see someone else repeatedly performing the task", visual modality); and imagine themselves singing a song (a Brazilian version of "happy birthday to you") as a control imagery task (Fig. 1). Before the experiment itself, the participants stood in the force platform for a short period of adaptation and were allowed to rise on their tiptoes and to imagine the task in kinesthetic and visual modalities until they felt comfortable. No specific instruction was given about the frequency or the velocity of executing or imagining the plantar flexion movement.

The sequence of the four above mentioned tasks composed a block which was repeated three times along the experimental session. Every block started with the execution task, followed by kinesthetic, visual and control tasks (first block); control, kinesthetic and visual tasks (second block); and visual, control and kinesthetic tasks (third block). Data collection started with a "go" signal and lasted for 30 s per task, thus ensuring reliability of posturographic measurement and between-task comparisons (Carpenter et al., 2001; Pinsault and Vuillerme, 2009). Evaluative reports (see below) were collected between the tasks. Each block lasted about 4 min. Participants sat on a chair for a 2 min-rest between blocks. Feet position was labeled in the force platform to ensure that the subjects would come back to the same position after rest.

Evaluative report

To infer about the temporal equivalence among plantar flexion execution and imagery tasks, after each task the participants reported the number of performed and imagined movement repetitions, respectively. The easiness to perform the imagery tasks was also measured using a scale designed by Hall and Martin (1997) where score 1 corresponded to very hard to imagine, and score 7 corresponded to very easy to imagine.

Posturography

Body sway was estimated by the measurement of the CoP using a force platform (Accusway^{PLUS}, AMTI, USA). The posturographic signals were sampled at 50 Hz and low pass filtered with a cutoff frequency at 5 Hz. Quantitative analysis of the posturographic signal was performed by calculating the elliptical area of displacement, as well as the standard deviation, mean frequency, and mean velocity of CoP displacements along the medial–lateral (ML) and anterior–posterior (AP) directions. Data analysis was performed with MATLAB 7 software (MathWorks, USA).

In a second approach, the rambling and trembling displacement components were obtained according to the method developed by Zatsiorsky and Duarte (1999). In brief, the rambling component was calculated by interpolating the instantaneous equilibrium points, defined as the position of CoP when the resulting horizontal force is equal to zero. The difference between the rambling and CoP trajectories was defined as the trembling component. According to Lafond et al. (2004), this decomposition technique of CoP time series provides a very good estimate of the center of gravity (CoG) position (rambling component) and of the CoP–CoG error (trembling component). From the rambling and trembling time series we calculated the standard deviation, mean frequency and mean velocity along the ML and AP directions.

EMG acquisition and analysis

Electromyographic (EMG) activity from the right *gastrocnemius lateralis*, a prime mover of plantar flexion execution (Lippert,