NeuroImage: Clinical 20 (2018) 177–187

Contents lists available at ScienceDirect

NeuroImage: Clinical

journal homepage: www.elsevier.com/locate/ynicl

A functional limitation to the lower limbs affects the neural bases of motor imagery of gait

Lucia Maria Sacheli[a,b,*], Laura Zapparoli[b], Matteo Preti[b], Carlo De Santis[a], Catia Pelosi[b], Nicola Ursino[b], Alberto Zerbi[b], Elena Stucovitz[b], Giuseppe Banfi[b,c], Eraldo Paulesu[a,b,*]

[a] University of Milano-Bicocca, Department of Psychology and Milan Center for Neuroscience (NeuroMI), Piazza dell'Ateneo Nuovo 1, 20126 Milan, Italy
[b] IRCCS Istituto Ortopedico Galeazzi, via Riccardo Galeazzi 4, 20161 Milan, Italy
[c] University Vita e Salute San Raffaele, Milan, Italy

ARTICLE INFO

Keywords:
Gait
Orthopaedic patients
Motor imagery
fMRI

ABSTRACT

Studies on athletes or neurological patients with motor disorders have shown a close link between motor experience and motor imagery skills. Here we evaluated whether a functional limitation due to a musculoskeletal disorder has an impact on the ability to mentally rehearse the motor patterns of walking, an overlearned and highly automatic behaviour. We assessed the behavioural performance (measured through mental chronometry tasks) and the neural signatures of motor imagery of gait in patients with chronic knee arthrosis and in age-matched, healthy controls. During fMRI, participants observed (i) stationary or (ii) moving videos of a path in a park shown in the first-person perspective: they were asked to imagine themselves (i) standing on or (ii) walking along the path, as if the camera were "their own eyes" (gait imagery (GI) task). In half of the trials, participants performed a dynamic gait imagery (DGI) task by combining foot movements with GI. Behavioural tests revealed a lower degree of isochrony between imagined and performed walking in the patients, indicating impairment in the ability to mentally rehearse gait motor patterns. Moreover, fMRI showed widespread hypoactivation during GI in motor planning (premotor and parietal) brain regions, the brainstem, and the cerebellum. Crucially, the performance of DGI had a modulatory effect on the patients and enhanced activation of the posterior parietal, brainstem, and cerebellar regions that the healthy controls recruited during the GI task. These findings show that functional limitations of peripheral origin may impact on gait motor representations, providing a rationale for cognitive rehabilitation protocols in patients with gait disorders of orthopaedic nature. The DGI task may be a suitable tool in this respect.

1. Introduction

Motor experience influences motor imagery ability: musicians and athletes alike show higher performance in motor imagery tasks for actions within their domain of expertise (Olsson et al., 2008; Lotze et al., 2003). Conversely, alterations of motor imagery accompany neurological disorders affecting the motor system (see Di Rienzo et al., 2014 for a review). What remains unclear is whether a peripheral limitation, e.g., due to a musculoskeletal disorder, might influence the ability to rehearse motor acts through motor imagery. Here we explored the instance of walking, which in adults becomes an overlearned and highly automatic behaviour dependent on both subcortical and cortical control.

Motor imagery is defined as a mental state in which real movements and the corresponding neural activity are internally evoked without overt muscular contraction (Jeannerod and Frak, 1999). A functional equivalence between motor representations involved in motor imagery and movement planning has been postulated on the basis of two bodies of evidence: first, the time required to mentally evoke an action during motor imagery correlates with the time required to actually perform the same action ("isochrony", Decety and Michel, 1989, as tested with so-called mental chronometry tasks); second, neurofunctional studies have shown that the same neural resources are systematically recruited during both motor imagery and the execution of a given action (see Hétu et al., 2013 for a review), as confirmed by studies on corticospinal excitability measured by transcranial magnetic stimulation (Li et al.,

Abbreviations: GI, Gait Imagery; DGI, Dynamic Gait Imagery

* Corresponding author at: University of Milano-Bicocca, Department of Psychology and Milan Center for Neuroscience (NeuroMI), Piazza dell'Ateneo Nuovo 1, 20126 Milan, Italy.

E-mail addresses: lucia.sacheli@unimib.it (L.M. Sacheli), eraldo.paulesu@unimib.it (E. Paulesu).

https://doi.org/10.1016/j.nicl.2018.07.003
Received 15 May 2018; Received in revised form 1 July 2018; Accepted 3 July 2018
Available online 05 July 2018

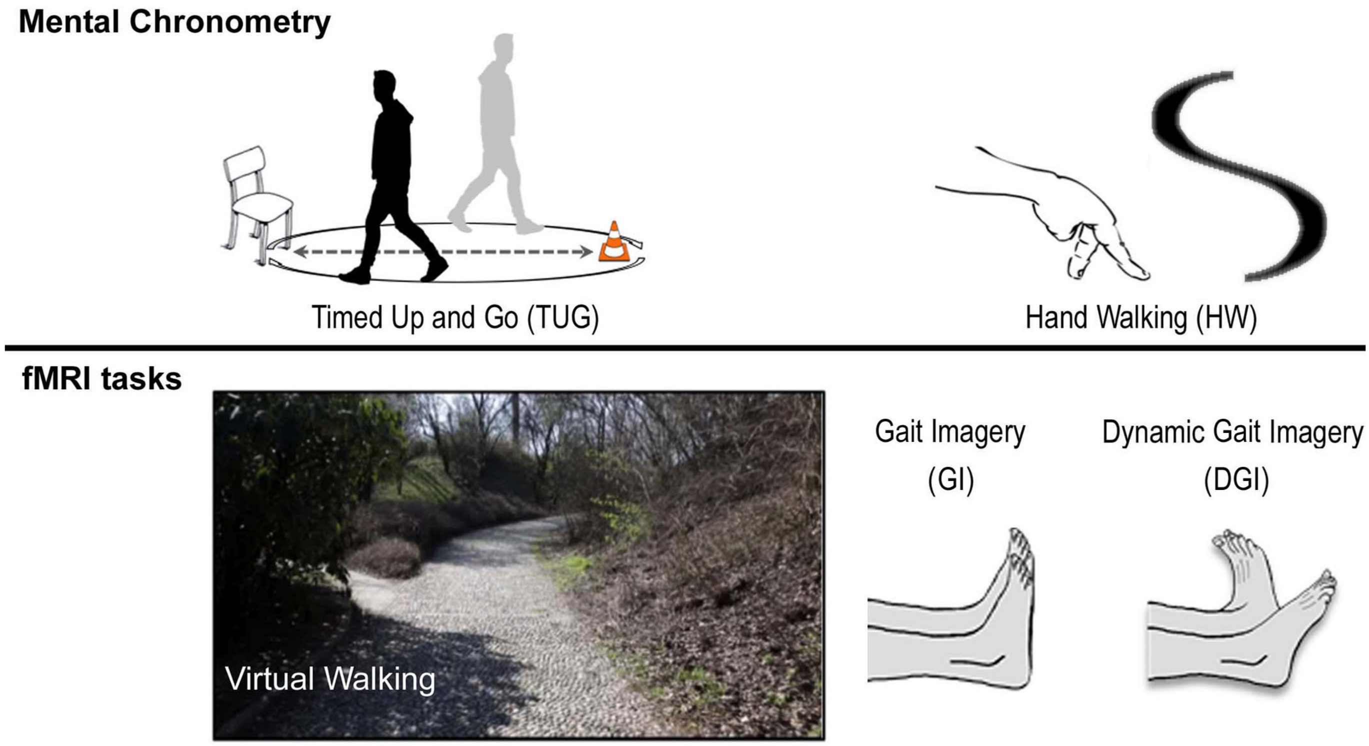

Fig. 1. The mental chronometry tasks performed outside the MRI scanner (upper panel) and the "virtual walking" task performed during fMRI (lower panel). The mental chronometry tasks included the timed up and go (TUG) task and a control task performed with the right dominant hand (hand-walking task). During fMRI, participants imagined themselves standing on or walking along a path in a park shown from the first-person perspective: the explicit motor imagery task was combined with overt foot movement in 50% of the trials (dynamic gait imagery, DGI), while in the other half of the trials the participants did not move their feet (gait imagery, GI).

2004; Fourkas et al., 2006) that also show a relationship between the strength of corticospinal activation during imagery and individuals' motor imagery abilities (Williams et al., 2012). Overall, these data suggest that motor imagery allows one to practice movements without the need to physically perform them. For this reason, motor imagery has proven valuable in a variety of circumstances, such as training in athletes or musicians, training of surgical skills, and post-stroke rehabilitation (see Schuster et al., 2011; Jackson et al., 2001). Motor imagery may be particularly useful in treating conditions where practical limitations such as biomechanical rigidity and reduced physical strength constrain physical training and increase the risk of injury or pain and fatigue.

Motor performance and motor imagery abilities are strictly interrelated. Motor imagery has been successfully applied in sport science to boost performance (see Ridderinkhof and Brass, 2015; Jones and Stuth, 1997): motor experts like athletes and musicians show a higher temporal correspondence between actual and imagined movements and more focused neural activations in motor areas when they mentally evoke actions in their domain of expertise (Olsson et al., 2008; Lotze et al., 2003). In this regard, task-specificity plays a crucial role, as motor imagery is based on task-specific motor representations that are only created through previous motor experience. Indeed, no one would be able to imagine actions that he/she is unable to perform, at least not using motor imagery. In such instances, people would most likely apply a visual strategy when asked to perform an imagery task (Olsson and Nyberg, 2010).

Motor dysfunctions impact on motor imagery abilities. It has been suggested (see Di Rienzo et al., 2014) that functional equivalence is completely lost in certain circumstances, e.g., after parietal lesion (Sirigu et al., 1995, 1996; Tomasino et al., 2003). However, in most pathological conditions motor imagery may not be deteriorated per se, rather it may be adjusted to the current state of the motor system (e.g., in spinal cord injury, Decety and Boisson, 1990; Fiori et al., 2014; Scandola et al., 2017; or in Parkinson's Disease, Dominey et al., 1995; Helmich et al., 2007; see di Rienzo et al., 2014 for a review). In these latter conditions, patients show impairments in their motor imagery abilities that are selective for the body districts and actions in which they show impaired performance. Motor imagery is thus considered an effective method for studying the quality of motor representations in disease conditions (Crammond, 1997). For instance, it can be applied to investigate whether a functional limitation of purely peripheral origin might impact on the quality of motor representations and is paralleled by a plastic reorganization of motor representations at the neural level.

Orthopaedic patients, with no history of major neurological disorder, represent a case of special interest for studying maladaptive brain plasticity following chronic disuse of a body district and defining the eventual benefit of mental training programmes in subjects with functional limitations. We recently tested patients with trapeziometacarpal osteoarthritis and found signs of maladaptive plasticity, as shown by brain activation during finger opposition tasks (Gandola et al., 2017). One could argue that the hand, and the precision grip in particular, has a special status for human survival (Napier and Napier, 1985; Napier, 1993), making it an apt tool for detecting brain abnormalities associated with chronic disuse. This raises the question whether similar signs of maladaptive brain plasticity could be found for actions performed with other body districts and specifically with the lower limbs.

This is the hypothesis that we tested in the present study: we investigated whether a peripheral limitation to the lower limbs due to an orthopaedic disorder (i.e., chronic knee arthrosis) might alter motor representations of lower limb movements as assessed by gait motor imagery tasks. Two characteristics of our sample merit attention: first, knee arthrosis causes a strictly localized functional limitation that is not accompanied by major central injury or by major dysfunction in