Please cite this article in press as: Di Rienzo F et al. Short-term effects of integrated motor imagery practice on muscle activation and force performance. Neuroscience (2015), http://dx.doi.org/10.1016/j.neuroscience.2015.07.080

*Neuroscience* xxx (2015) xxx–xxx

# SHORT-TERM EFFECTS OF INTEGRATED MOTOR IMAGERY PRACTICE ON MUSCLE ACTIVATION AND FORCE PERFORMANCE

**F. DI RIENZO,** [a*] **Y. BLACHE,** [a,b] **T. F. D. KANTHACK,** [a,c] **K. MONTEIL,** [a] **C. COLLET** [a] **AND A. GUILLOT** [a,d]

[a] *Université de Lyon, Université Claude Bernard Lyon 1, Centre de Recherche et d'Innovation sur le Sport, EA 647, 27-29 Boulevard du 11 Novembre 1918, 69622 Villeurbanne Cedex, France*

[b] *University of Montreal, Simulation & Movement Modeling Laboratory, Department of Kinesiology, Canada*

[c] *CAPES Foundation, Ministry of Education of Brazil, Brasília, Distrito Federal, Brazil*

[d] *Institut Universitaire de France, 103 Boulevard Saint-Michel, 75005 Paris, France*

**Abstract—The effect of motor imagery (MI) practice on isometric force development is well-documented. However, whether practicing MI during the rest periods of physical training improves the forthcoming performance remains unexplored. We involved 18 athletes in a counterbalanced design including three physical training sessions scheduled over five consecutive days. Training involved 10 maximal isometric contractions against a force plate, with the elbow at 90°. During two sessions, we integrated MI practice (focusing on either muscle activation or relaxation) during the inter-trial rest periods. We measured muscle performance from force plate and electromyograms of the *biceps brachii* and *anterior deltoideus*. We continuously monitored electrodermal activity (EDA) to control sympathetic nervous system activity. MI of muscle activation resulted in higher isometric force as compared to both MI of muscle relaxation and passive recovery (respectively +2.1% and +3.5%). MI practice of muscle relaxation also outperformed the control condition (+1.9%). Increased activation of the *biceps brachii* was recorded under both MI practice conditions compared to control. *Biceps brachii* activation was similar between the two MI practice conditions, but electromyography revealed a marginal trend toward greater activation of the *anterior deltoideus* during MI practice of muscle activation. EDA and self-reports indicated that these effects were independent from physiological arousal and motivation. These results might account for priming effects of MI practice yielding to higher muscle activation and force performance. Present findings may be of interest for applications in sports training and neurologic rehabilitation.**

**Key words: mental practice, force development, training, rehabilitation.**

## INTRODUCTION

Motor imagery (MI), i.e., the mental rehearsal of an action without any overt execution, is a cognitive operation involving executive parts of the brain motor system (for reviews, see Lotze and Halsband, 2006; Munzert et al., 2009). MI recruits cerebral substrates controlling the actual preparation and execution of the movement including primary somatosensory and motor cortices (Munzert et al., 2009). In several experiments, subliminal muscle activations were detected during MI. Neuromuscular activity was primarily recorded within the prime movers of the imagined movement (Bird, 1984; Boschker, 2001). Despite challenging data (e.g., Personnier et al., 2010), subliminal muscle activation was found to increase according to the intensity of the imagined contraction (Bonnet et al., 1997; Boschker, 2001). The psychoneuromuscular theory early postulated that similar electromyographic patterns could occur during both physical practice (PP) and MI (Jacobson, 1930, 1932; Wehner et al., 1984), albeit with reduced magnitude (Gandevia et al., 1997). Subliminal muscle activity was even found to reflect the type of muscle contraction imagined by the participant (i.e., isometric, concentric and excentric; Guillot et al., 2007), while brain activations during MI appeared to covariate with the imagined force level (Mizuguchi et al., 2014). Taken together, these data support that subliminal muscle activation during MI might result from an incomplete inhibition of the somatic motor command (see Jeannerod, 1994 for a pioneering discussion).

Somatic motor commands addressed to muscles are paralleled by neurovegetative commands to internal organs and smooth muscles of blood vessels through the parasympathetic and sympathetic pathways. The autonomic nervous system permanently adjusts the metabolic activity to face forthcoming demands in energy. The autonomic correlates of PP are well-reproduced during MI. For instance, Decety et al. (1991) provided evidence that both heart and respiratory rates increased proportionally according to the imagined walking speed. Autonomic nervous system recordings can thus be used to monitor MI in real time (for a review, see Collet et al., 2013).

Due to structural and functional similarities with PP, MI practice has been used as a training method to enhance

---

*Corresponding author. Address: Centre de Recherche et d'Innovation sur le Sport, EA 647, Université Claude Bernard Lyon 1, 27-29 Boulevard du 11 Novembre 1918, 69622 Villeurbanne Cedex, France. Tel: +33-4-72-43-16-25; fax: +33-4-72-44-80-10.
E-mail address: franck.di-rienzo@univ-lyon1.fr (F. Di Rienzo).

*Abbreviations:* EDA, electrodermal activity; EDR, electrodermal responses; EMG, electromyogram; iEMG, integrated electromyogram; MI, motor imagery.

http://dx.doi.org/10.1016/j.neuroscience.2015.07.080
0306-4522/

motor performance (Jackson et al., 2001; Morris et al., 2005). MI practice can facilitate motor learning and improve motor recovery after injury (for an overview, see Guillot and Collet, 2008). A more limited number of studies investigated its effects on strength. The pioneering study addressing this issue provided evidence that a 30-min session of MI practice increased the isometric strength of the quadriceps by 16% as compared to a control group not subjected to any form of physical or mental training (Cornwall et al., 1991). Most subsequent experiments yielded positive effects of MI practice, primarily on the development of maximal isometric strength (Yue and Cole, 1992; Smith et al., 2003; Wright and Smith, 2009). Gains usually ranged from 10% to 30% on both distal and proximal muscles of the upper limb (Yue and Cole, 1992; Wright and Smith, 2009). There is a general consensus that strength gains were of central origin, and occurred in the absence of any peripheral change, e.g. muscle hypertrophy (Yue and Cole, 1992; Ranganathan et al., 2004). Improvements may be grounded in cortical neuroplasticity, i.e., the capacity of neurons to reorganize their connectivity in response to the behavioral demand, hence leading to more efficient drive of motor units (e.g., spatial recruitment and stimulation intensities). Ranganathan et al. (2004) earlier reported a direct relationship between changes in cortical motor output and muscle performance after MI practice. Similarly, Yao et al. (2013) confirmed that kinesthetic MI practice of maximal isometric force increased the maximal isometric force of elbow flexors through cortical motor and pre-motor neuroadaptations.

To date, most studies delivered MI practice interventions alone (Cornwall et al., 1991; Yue and Cole, 1992; Ranganathan et al., 2004), or in addition to physical training (e.g., Wright and Smith, 2009; Reiser et al., 2011). Only few investigated the impact of *embedding* MI practice into actual training of strength (e.g., Lebon et al., 2010). The immediate effects of MI practice during inter-trial periods of strength training sessions has not yet been investigated. This is somehow surprising because MI practice frameworks usually recommend practicing in combination with PP and in a similar context to that of actual training (Holmes and Collins, 2001; Guillot et al., 2005; Wright and Smith, 2009). In the present experiment, we addressed whether MI practice during rest periods of physical training improved maximal isometric force. We specifically tested the selective effects of MI practice focusing either on muscle activation or relaxation on force and muscle fatigue as compared to a passive recovery condition. We hypothesized that activating MI practice would outperform both relaxing MI practice and passive recovery since it involved a specific focus on the voluntary drive addressed to the somatic effectors of the force task. MI practice focused on muscle relaxation was expected to control for attention/placebo effects. Passive recovery was finally considered the reference condition since it is the usual modality of recovery during inter-trial periods. We aimed to provide original insights into the rules of MI practice for future applications in sports and rehabilitation (e.g., Lebon et al., 2012). A fundamental question finally relates to the potential *immediate* benefits of MI practice on muscle activation, by contrast to "*offline*" gains obtained after extended periods of MI practice decoupled from the immediate context of training.

## EXPERIMENTAL PROCEDURES

### Participants

Participants ($n = 18$, mean age = 19.31 ± 1.25 years) were recruited from the Faculty of Sports Sciences of the University Claude Bernard Lyon 1 (F-69100, Villeurbanne). All were right-handed inter-regional male athletes in terrestrial sports (i.e., tennis, volleyball, handball and climbing). They had a background of 2 years in upper limb muscle training in their own competing activities. No information concerning the purpose of the study was provided until after completion of the design. The local review board approved the experiment, and participants' written consent was obtained according to the statements of the Declaration of Helsinki (1982).

### Experimental design

The design was scheduled over five consecutive days and included three physical training sessions involving 10 trials of maximal isometric contractions (see below). To avoid circadian effects, training sessions were performed at the same time of the day (12 am before lunch), lasted 30 min, and were separated from each other by 48 h (i.e., one entire day interposed between each recording day). Experimental conditions ($n = 3$) were delivered during inter-trial periods of the training session: (i) MI practice of muscle activation (activating MI), (ii) MI practice of muscle relaxation (relaxing MI), and (iii) Passive recovery where the participants listened passively to three blocks of information about the international sports news (12 s each; control). Relaxing MI was expected to control for placebo effects (e.g., athletes' expectations toward the efficacy of MI practice) since it involved a specific focus on the *biceps brachii* recovery between force trials. The control condition aimed to control for the attention paid to audio instructions during MI conditions. To overcome carryover effects (e.g., residual muscle fatigue from one training session to another), we implemented a fully counterbalanced design with three participants assigned to each of the six possible order conditions (block randomization).

### Strength training sessions

Participants sat on a bench; warmed-up and familiarized with experimental instructions for 15 min (see Appendix A, "*Warm-up*" and "*Familiarization*" for further description). Then, they were requested to perform 10 successive maximal flexions of their dominant elbow against an immobile force platform placed in front of them (isometric contractions) (Fig. 1A). They sustained their effort during 12 s. We used an auditory stimulus (110 Hz–50 dB) to trigger each trial start and end. Hand position was

Please cite this article in press as: Di Rienzo F et al. Short-term effects of integrated motor imagery practice on muscle activation and force performance. Neuroscience (2015), http://dx.doi.org/10.1016/j.neuroscience.2015.07.080