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RESEARCH ARTICLE

The influence of imagery capacity in motor performance improvement

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Abstract Motor imagery (MI) training improves motor performance, but the inter-individual variability of this improvement remains still unexplored. In this study, we tested the influence of imagery ability on the performance improvement following MI training. Twenty participants were randomly distributed into the MI or control group. They actually performed, at pre- and post-test sessions, a revisited version of the Nine Hole Peg Test, a speed-accuracy trade-off task, commonly used in clinics. Between the tests, the MI group mentally trained on the task (5 blocks of 10 trials), while the control group watched a non-emotional documentary. Before and during MI training, we tested the imagery ability of the MI group, by the revised version of Movement Imagery Questionnaire and by the estimation of vividness for the movement task at each block (subjective evaluation—SE). In the post-test, the MI group significantly decreased the movement duration by $-12.1 \pm 5.7\%$ ($P < 0.001$), whereas the control group did not ($-2.68 \pm 5\%$, $P = 0.68$). For the MI group, the percentage of improvement was correlated neither to the MIQ-R nor to the SE reported after block 1. However, we observed an evolution of the SE during training, with a positive correlation between performance improvement and SE at block 4 ($R = 0.61$, $P = 0.03$) and at block 5 ($R = 0.68$, $P = 0.04$). The current study shows that motor performance may be positively influenced, whilst not predicted, by the capacity to form vivid movement images throughout the mental training. These findings are of interest for clinical interventions using MI as a complementary rehabilitation tool.

Keywords Motor imagery · Mental practice · Motor performance improvement · Imagery capacity

Introduction

Motor imagery (MI) is the mental simulation of an action without any corresponding motor output (Jeannerod 1994; Decety and Grèzes 1999). Behavioral and neurophysiological studies have shown many similarities between executed and imagined movements. At the behavioral level, by means of the mental chronometry paradigm, it has been observed a temporal congruence between the production of a movement and its mental simulation (Decety et al. 1989; Guillot and Collet 2005; Gueugneau et al. 2008; Papaxanthis et al. 2012). Concerning the neurophysiological level, many investigations have confirmed a common neural support between mental and actual states. Notably, similar activations have been found in the premotor cortex, the supplementary area, the inferior and superior parietal lobule, the cerebellum, the basal ganglia, and the prefrontal cortex (Hétu et al. 2013). In addition, transcranial magnetic stimulation studies have shown corticospinal facilitation during MI (Rossini et al. 1999; Yahagi and Kasai 1999; Lebon et al. 2012; Avanzino et al. 2015). This facilitation is muscle- (Facchini et al. 2002), time- (Fadiga et al. 1998), arm- (Gandrey et al. 2013), and content- (Mizuguchi et al. 2013) specific. Recently, Grosprêtre et al. (2016) showed that during MI, a subliminal motor output was driven along the corticospinal track to reach spinal structures without activating alpha-motoneurons.

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Mental practice with MI, which is the mental repetition of a movement, can improve several aspects of motor performance. For instance, MI practice can increase muscular strength (Yue and Cole 1992; Ranganathan et al. 2004; Lebon et al. 2010), prevent the loss of muscle force during immobilization (Clark et al. 2015), and enhance movement speed and accuracy (Yágüez et al. 1998; Gentili et al. 2006; Allami et al. 2008; Gentili et al. 2010; Gueugneau and Papaxanthis 2010; Gentili and Papaxanthis 2015; Gueugneau et al. 2016). Similar positive results have been found in sports (Driskell et al. 1994) and motor rehabilitation (Jackson et al. 2001; Malouin and Richards 2010; Malouin et al. 2013). Frank et al. (2014, 2015) showed the positive influence of MI practice on the representation structure of complex actions. A combination of physical and mental practice would lead to better structure and elaborate representations, compared to physical practice alone.

Albeit the proven effects of MI practice on motor performance, how inter-individual differences regarding the capacity to imagine a movement influence motor performance improvement by MI practice is still under debate (Goss et al. 1986; Lovell and Collins 2001; Lebon et al. 2010; Avanzino et al. 2015). For example, in a flexibility training study, Guillot et al. (2010) observed no correlation between individual imagery ability measured by questionnaires at the beginning of the training and improvement in flexibility. On the contrary, Vergeer and Roberts (2006a, b) showed a positive correlation between imagery vividness, measured throughout the intervention, and improvement in movement flexibility. The time to which imagery vividness is measured, i.e. at the beginning or at the end of training, may be of importance. Watt et al. (2002) defined imagery ability 'as the capacity of the individual to create images, and is typically evaluated in terms of generational, sensorial, and emotional qualities'. The subjective evaluation of imagery quality by means of questionnaires has been a central concern in MI investigations. These questionnaires aimed at auto-evaluating the vividness of MI through different items (McAvinue and Robertson 2008) and revealed important inter-individual differences (Hall 1985; Madan and Singhal 2012). These differences are also noticeable at the neural level. For instance, Guillot et al. (2008) observed greater activations of the parietal and ventrolateral premotor regions (regions strongly involved in the generation of mental images) for the subjects with better motor imagery abilities, measured via physiological (skin conductance and heart rate), behavioral (mental chronometry), and psychological (questionnaires) variables. Likewise, Lebon et al. (2012) demonstrated that the modulation of corticospinal excitability during MI depends on imagery quality; the muscle and time-specificity of MI is more pronounced for individuals with greater imagery ability. Interestingly, some studies showed a positive effect of MI practice on imagery capacities, assessed with questionnaires (Rodgers et al. 1991; Calmels et al. 2004; McAvinue and Robertson 2009; Williams et al. 2013; Anuar et al. 2016).

Whether imagery ability is determinant for motor performance improvement by MI practice is a central question in neuro-rehabilitation. The concern relies on the selection or not of patients in clinical trials based on this subjective estimation of imagery quality. Several studies used the score at questionnaires to allow patients to follow the mental training program (Malouin et al. 2013). The purpose of the present study was to determine whether the imagery capacity in healthy individuals could influence motor performance improvement following mental practice. Do individuals qualified as best imagers have better chances to improve their motor performance following MI practice, and inversely? In the previous studies, the authors divided the subjects, at least, into two groups: 'good' and 'poor' imagers. In the current study, we studied the continuum between imagery capacities and performance improvement following MI practice, without assigning a subject to a group. We focused on a dexterity manual task commonly used in clinical practice, the Nine Hole Peg Test (NHPT), to estimate the influence of imagery ability on motor performance after a pure MI practice. We asked the participants to perform as fast as possible sequences of movements in a pre-determined order, before and after mental practice. With different subjective evaluations, we measured the individual capacity to imagined movements. We hypothesized that a greater self-estimation of MI ability could lead to a better performance improvement after the training.

Experimental procedures

Participants

Twenty right-handed healthy participants (mean age 27 ± 5 years old, 10 females), without neurological or physical disorders, were recruited for the current experiment after giving their consent. They were distributed into two groups: the mental training with motor imagery (MI) group ($n = 13$) and the control group ($n = 7$). Experimental protocol and procedures were approved by the local Ethics Committee of the Université de Bourgogne.

Experimental device and procedure

The participants were comfortably seated on a chair in front of a table; the distance between the participants' chest and the table was 20 cm. They were asked to perform a revisited version of the NHPT. The NHPT is broadly used in clinical practice to measure the ability of patients to perform a fine motor task. We modified the original task to increase its difficulty and duration. The revisited version required moving the nine sticks as fast as possible into nine holes in a pre-determined order and then removing them back into a specific box (see Fig. 1a). Each hole corresponded to a specific letter.

In our protocol, there were two test sessions (pre-test and post-test) and two tasks (the motor task and the transfer task). In the motor task, the participants started moving the stick from the hole 1 to the hole A, then from the hole 2 to the hole B, etc. Once all sticks were placed into the corresponding holes, the participants had to immediately put them, one-by-one, into the Box 1, starting with the stick positioned in the hole A. We called this task 'motor', because the participants of the MI group mentally repeated this task during the training session (see below). In the transfer task, we measured the potential transfer of performance improvement by mental practice from the motor task into another task, which was the mirror image of the first task; namely, the participants were instructed to move the sticks from the letters to the corresponding numbers (from A to 1, B to 2, etc.), and then back into the Box 2. Note that none of the groups was trained in this task.

The participants of the two groups performed three actual trials for each task in the pre-test and post-test sessions (see Fig. 1b). Note that each trial included 9 arm movements; therefore, participants carried out 36 movements in the pre-test and post-test sessions. We recorded the duration for each trial. The experimenter started the timer when the participant touched the first stick and stopped it when the last stick was put in the box.

The MI group was mentally trained on the motor task for about 30 min. The participants were instructed to imagine themselves performing the task as fast as possible, combining the kinesthetic and visual (first-person perspective) modality. To ensure that all participants carried out the training phase correctly, we provided the following instructions: "try to imagine yourself performing the motor task, by feeling the body sensation as if you were doing it and perceiving the different movements just as if you had a camera on your head". They performed five blocks of ten trials, with 1-min rest between blocks to avoid mental fatigue (Rozand et al. 2016). The experimenter recorded the duration of each imagined movement; the participant gave a verbal signal when he/she started and finished imagining. After each block of imagined trials, the participants reported the subjective estimation (SE) of the imagined movement quality by means of a 7-point Likert scale (1: very hard to feel and see the movement, 7: very easy to feel and see the movement, 2–6: intermediate score).

Before the beginning of the experimental session, the participants in the MI group completed the revised version of the Motor Imagery Questionnaire (MIQ-R; Hall and Martin 1997), which assess the visual and kinesthetic movement imagery abilities on four different movements (minimum score 8; maximum score 56). The control group only watched a non-emotional documentary ("Home", directed by Y. Arthus-Bertrand, 2009), for 30 min (the approximate time of the mental training). The control experiment was performed to test whether this non-demanding cognitive task could reduce the duration of the speed–accuracy trade-off task (Rozand et al. 2015).

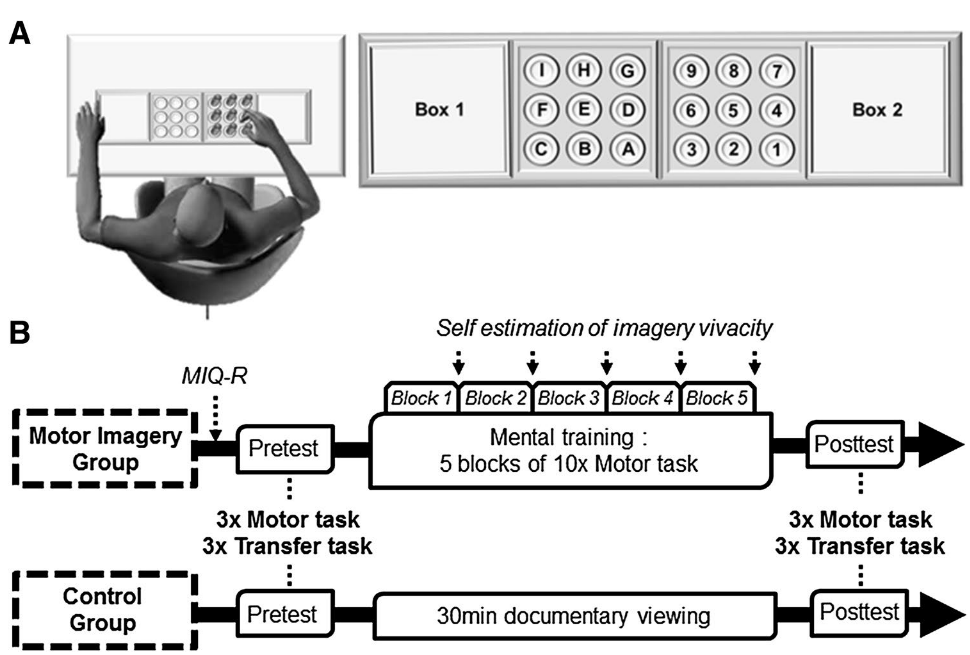

Fig. 1 Experimental design (**a**) and experimental procedure (**b**). *MIQ-R* revised version of the Movement Imagery Questionnaire

Statistical analysis

First, the normality of the data was verified by the Shapiro–Wilk test. As duration of actual movements in pre-test and post-test sessions did not follow normal distribution ($P < 0.05$), we used non-parametric tests. We first compared the initial performance (pre-test) of each group, for each task separately, with Mann–Whitney *U* tests. To test the performance improvement between pre-test and post-test, we conducted Wilcoxon tests, for each task (motor and transfer) and each group (MI and control). We tested the correlation between performance improvement [(Post − Pre)/Pre × 100] of the motor and the transfer task with a linear regression analysis. Cohen's effect size (*ES*) was calculated for each condition.

Imagined movement durations during mental training followed normal distribution ($P > 0.05$) and sphericity was respected (Mauchly's test, $P > 0.05$). We analyzed the evolution of MI duration during training using a one-way repeated-measurement ANOVA, with *BLOCKS* as within-subject factor (block 1–5). We used post hoc tests with Bonferroni correction when appropriated. We tested the correlation between the motor performance improvement and the evolution of MI duration during training [(MI duration block 1 − MI duration block 5)/MI duration block 1 × 100].

To determine whether the subjective estimation of imagery quality at the beginning of the training could predict the performance improvement, we used linear regression analysis to correlate the percentage of performance enhancement with the MIQ-R score and with the SE score of the first training block. Then, to test the influence of SE on motor performance throughout the training, we correlated the percentage of performance enhancement with SE measured after each other block.

Statistical analysis was performed using STATISTICA (8.0 version; Stat-Soft, Tulsa, OK, USA). The level of significance was accepted at $P < 0.05$. Data are presented as mean (SD) with 95% confidence intervals (CI).

Results

Motor performance improvement after MI practice

Figure 2 illustrates mean durations (+SE) for both groups and both motor tasks in pre-test and post-test sessions. Regarding the initial performance (pre-test), the Mann–Whitney *U* test revealed no significant difference between the MI and the control group for both the motor task ($P = 0.61$; $Z = 0.515$) and the transfer ($P = 0.72$; $Z = 0.357$) task. When comparing the motor improvement between the pre-test and post-test sessions, we found that the MI Group significantly decreased the duration of actual movements (motor task: −12.1 ± 5.7%, 95% CI [−15.5; −8.7], $Z = 3.33$, $P < 0.001$, ES = 0.99; transfer task: −7.1 ± 7.5%, 95% CI [−11.6; −2.5], $Z = 2.77$, $P < 0.01$, ES = 0.61). On the contrary, we did not observe any improvement (less than 3%) for the control group in both tasks (−2.7 ± 5.0%, 95% CI [−7.3; 1.9], $Z = 0.41$; $P = 0.68$; ES = 0.29 for the motor task and −2.3 ± 4.8%, 95% CI [−6.8; 2.2], $Z = 1.51$; $P = 0.13$; ES = 0.26 for the transfer task). Furthermore, we observed a positive correlation between the percentages of improvement for the motor and the transfer task ($R = 0.61$, $P = 0.03$).

Evolution of MI duration during the training period

Figure 3 shows mean durations of imagined movements for the five blocks during mental training. The repeated-measurements ANOVA revealed a progressive decrease of imagined movement duration during the mental training period ($F_{4,48} = 4.81$, $P < 0.01$). Bonferroni post hoc analysis showed differences between block 1 and 3 ($P = 0.03$) and block 1 and 5 ($P < 0.01$). However, the percentage of MI duration decrease did not significantly correlate with the percentage of motor performance improvement ($R = 0.41$, $P = 0.16$).

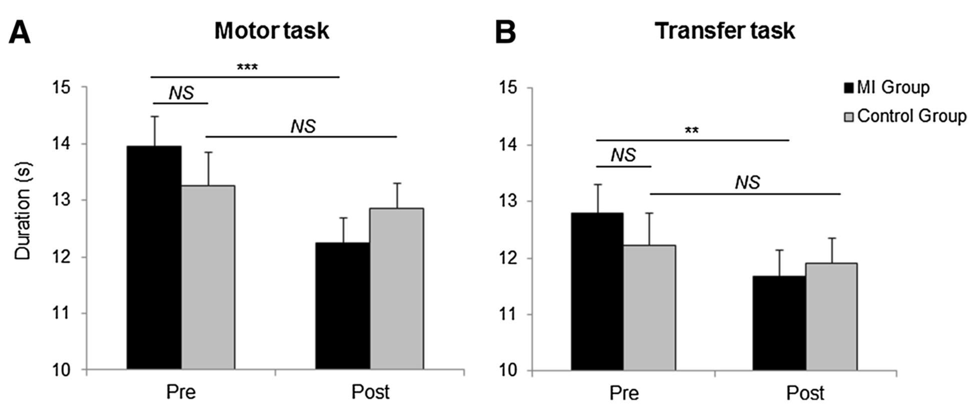

Fig. 2 Mean duration and SD for the Nine Hole Peg Test. Duration decreased between the pre-test and post-test for the MI Group (mental training group), but not for the control group, for both the motor and transfer tasks. ** $P < 0.01$, *** $P < 0.001$, *NS* non-significant

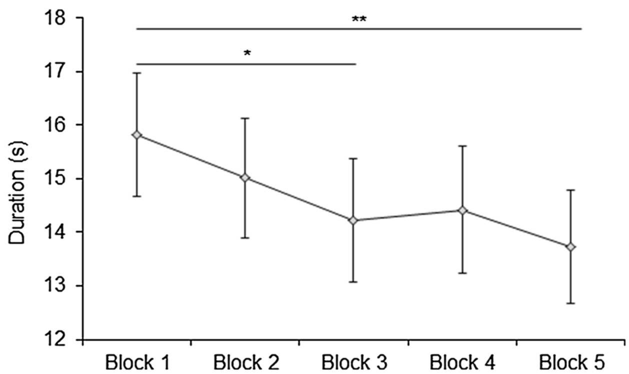

Fig. 3 Mean duration and SD of imagined movements for each block. Imagined durations progressively decreased with blocks. * $P < 0.05$, ** $P < 0.01$

Influence of imagery ability on motor performance

Table 1 presents scores of imagery quality (MIQ-R and SE) before and during mental training. At first, we wanted to determine whether these scores could predict the improvement in movement speed in the motor task. We did not find any correlation between the MIQ-R score and the percentage of performance improvement ($R = 0.41$; $P = 0.17$; Fig. 4a). Similarly, we did not find any correlation between the SE measured at the beginning of the training (block 1) and the percentage of performance improvement ($R = 0.44$; $P = 0.13$; Fig. 4b).

Finally, we aimed at determining the influence of SE score during the training on performance (Fig. 4c). Interestingly, we found that the correlation between SE and performance improvement progressively increased for block 2 ($R = 0.48$; $P = 0.1$) and block 3 ($R = 0.49$; $P = 0.09$), and became significant for block 4 ($R = 0.61$, $P = 0.03$) and block 5 ($R = 0.58$, $P = 0.04$).

Discussion

The main purpose of this study was to investigate whether self-estimation of imagery capacity could influence the performance enhancement following mental practice. The results showed that the subjective evaluation of imagery quality measured at the beginning of the training was not a reliable predictor of the increase of movement speed observed after MI training. However, it appeared that the dynamic evolution of the self-estimation throughout the training could influence motor performance.

Motor imagery practice improves motor performance

The decrease of actual movement duration for the MI group suggests a beneficial effect of MI training in motor performance. This result is in accordance with the previous studies, demonstrating the positive impact of MI practice on motor performance improvement (Yue and Cole 1992; Yágüez et al. 1998; Gentili et al. 2006; Robin et al. 2007; Allami et al. 2008; Avanzino et al. 2009; Gentili et al. 2010; Lebon et al. 2010; Gentili and Papaxanthis 2015). The absence of motor improvement for the control group further confirms the specific effect of MI practice on performance improvement. Interestingly, we also observed a transfer of learning for the transfer task, in which participants realized a mirror movement of the motor task. Indeed, movement duration in the post-test session was significantly faster than in the pre-test session, only for the MI group. Moreover, we found a positive correlation between the performance improvements observed in both tasks: the better the performance in the motor task, the better the performance in the transfer task. This result corroborates the generalization of motor performance improvement through MI practice observed by Gentili et al. (2006). In their study, the subjects were instructed to point with the whole arm toward several targets following two different paths (right and left paths), but they were trained only on the right path. Note that arm dynamics (inertial and gravity forces) dramatically differed between the two pointing paths. The results showed a significant decrease of movement duration after mental practice for both the right and the left paths, indicating that arm dynamics are taken into account during MI training. Our study further corroborates this finding by showing the transfer of motor performance improvement by MI practice in a clinical task.

Table 1 Scores of imagery quality before and during mental training

	MIQ-R	SE				
	Before training	Block 1	Block 2	Block 3	Block 4	Block 5
Mean (SD)	46.9 (5.3)	4.8 (0.8)	5.5 (0.8)	5.3 (1.1)	5.4 (0.9)	5.2 (1.2)
95% CI	43.7, 50.1	4.3, 5.3	5.1, 6.0	4.6, 6.0	4.9, 5.9	4.4, 5.9
Max	54	6	7	7	6	7
Min	38	4	4	3	4	3

MIQ-R revised version of the Movement Imagery Questionnaire, *SE* self-estimation of imagery quality of the motor task after each training block

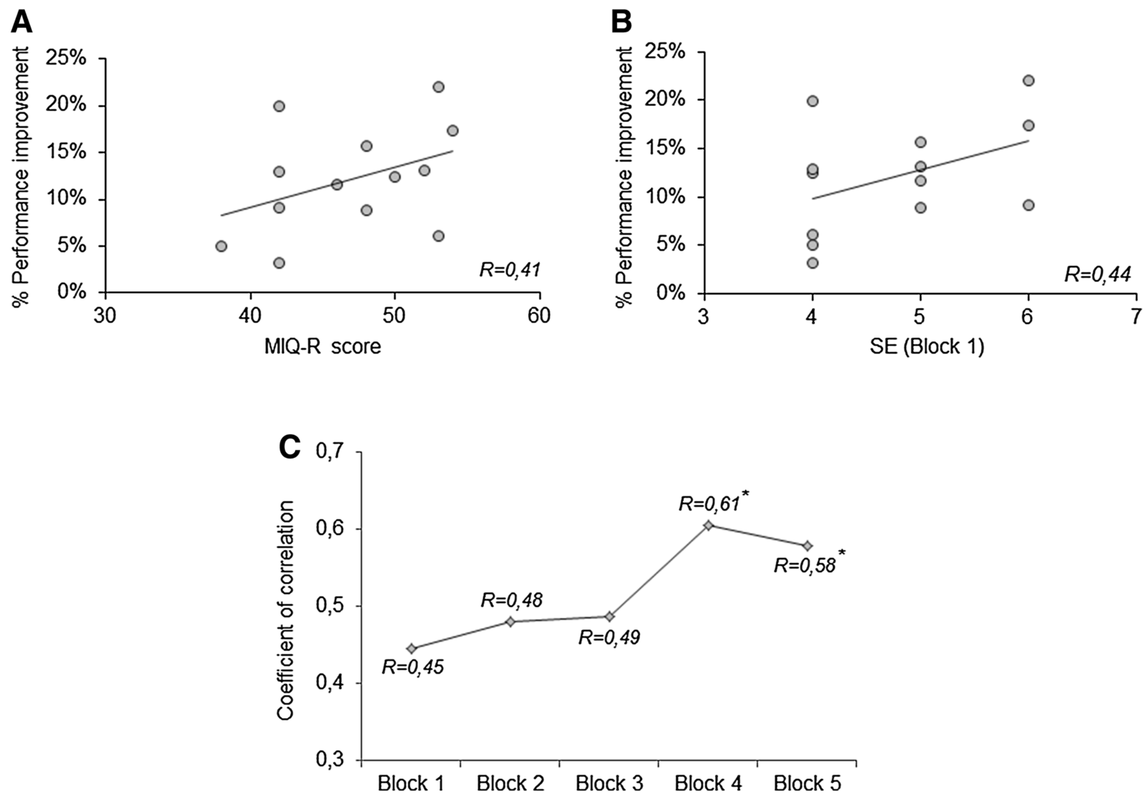

Fig. 4 **a** Correlation between MIQ-R score and percentage of performance improvement. **b** Correlation between SE score at the block 1 and percentage of performance improvement. **c** Evolution of the correlation between SE score during the training and %performance improvement. * $P < 0.05$

This aspect confirms the common neurocognitive mechanisms between physical and mental practices. Generalization is a well-known mechanism of actual motor learning (Shadmehr and Mussa-Ivaldi 1994; Goodbody and Wolpert 1998; Shadmehr et al. 2010): the central nervous system develops a new sensorimotor map that associates the desired hand trajectory, the external or internal forces, and the corresponding motor commands, thus allowing a transfer of motor learning to other contexts.

The concept of internal models offers the theoretical basis for understanding the performance enhancement following mental practice (Miall and Wolpert 1996; Wolpert and Flanagan 2001; Wolpert et al. 2011). During physical practice, the internal forward model receives a copy of the motor command (the efferent copy) and the sensory information concerning the initial state of the arm and predicts the future states. During MI, subjects prepare but inhibit the motor command before it reaches the muscular level; however, the efferent copy and the initial state are still available to the motor system for sensorimotor predictions. These predictions during MI practice may contribute to the performance enhancement observed during subsequent movement execution.

Influence of imagery ability on motor performance

Although internal model theory nicely explains the underlined neural mechanisms of motor performance improvement by mental practice, the subjective evaluation of the imagery capacity may be of importance in motor performance improvement for complex tasks. Here, we evaluated the imagery capacity with a general and well-accepted questionnaire, the MIQ-R (Hall and Martin 1997). Participants were ranked with the score which they obtained when self-estimating their imagery quality for generic movements. As demonstrated in the previous studies using subjective evaluations of imagery capacities (Vergeer and Roberts 2006a, b; Guillot et al. 2010), we did not find any correlation between the MIQ-R score and the performance enhancement observed after the mental training. The participants considered as ‘best imagers’ at the MIQ-R did not necessarily show the best performance increase. However, this result remains questionable. Indeed, in their study on finger opposition movements, Avanzino et al. (2015) showed a positive correlation between speed improvement and MIQ-R score. A possible explanation would consider the type of movement to be learned. For the current task, a speed-accuracy trade-off task, the participants had to integrate several motor components to be efficient. Indeed, they had to prepare the movement taking into account the spatial characteristics of the targets and the kinematics components of the movement (multi-joint action with several phases of acceleration/deceleration). In contrast, in Avanzino et al.'s study, participants had to repeatedly tap the thumb with the index finger as fast as possible.

Concerning our study, one could argue that the components of generic movements in the MIQ-R were too different from the movement learned in the experimental task (NHPT). Thus, we also analyzed the possible correlation between the performance improvement on the trained task and the self-estimation of the imagery capacity on the same task (by means of a 7-point Likert scale, the same as MIQ-R). Nonetheless, as for the correlation with the MIQ-R, performance improvement was not correlated to the self-estimation measured at the beginning of MI training, i.e., at block 1. These findings demonstrate that the self-estimation of imagery capacity, for generic and specific movements, is not a reliable predictor of performance improvement following mental practice for this task.

Interestingly, in the current study, we observed a progressive positive correlation between the performance improvement and the score of the subjective estimation of each block throughout the training, being significant from Block 4. At the first training block, participants who presented the better estimation of their imagery capacity were not necessarily those who finally had better performance increase. However, at the last training block, the participants with the better estimation of their imagery capacity showed the greatest performance improvement. This progressive correlation is supported by neurophysiological data, which showed that "good" imagers respect muscle- and time-specificity of MI, while "poor" imagers increase the level of corticospinal excitability in a general manner (Lebon et al. 2012). With practice, the neural network during MI seems to become more specific. A distinct cortical pattern has been identified between "good" and "poor" imagers, with greater activations in the motor network for the formers (Guillot et al. 2008). One study showed that high kinesthetic imagers have a greater learning rate, but when combining physical and kinesthetic imagined movements (Goss et al. 1986). This study did not predict motor performance with imagery ability but demonstrated that individuals with greater imagery ability better used the sensory feedbacks provided by each actual trial to reproduce the motor pattern of the task. The current findings suggest that the evolution of imagery ability may influence the benefits associated with MI practice through an increase in neural specificity. As a dynamic process, the content of the imagined movement evolved during MI training. This concept refers to the Learning component of the PETTLEP model in which the content of the image should be adapted to the changing skills of individuals during practice (Wakefield and Smith 2012). For a practical point of view, the imagers should adapt the content of the imagined movement to the expected sensorimotor consequences of the skilled movement.

Conclusions

In this study, we confirmed that MI practice increased motor performance in a motor task used in clinical practice. The subjective estimation measured before the training did not predict the performance improvement, and should not be an exclusion criterion in MI training studies, though the evolution of the subjective estimation throughout the training may positively influence this improvement. This result suggests that individuals with moderate imagery ability can improve their performance after a single session of MI practice. Furthermore, it seems that MI training is a dynamic process: improvement in imagery ability during the training leads to better improvement after the training. Therefore, focusing on the quality of motor images during mental training is more important than the initial level of imagery ability. We suggest this parameter to be emphasized in MI training protocols. A limit of this study is that it was addressed to healthy individuals with moderate-to-good imagery abilities (mean score at MIQ-R = 46.9 (5.3), min = 38, max = 54; for a maximal possible score of 56). To further explore the question, it would be of interest to test the influence of imagery ability in patients with cognitive and/or motor impairments and during multiple sessions of MI training.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interest.

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