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Research report

A prolonged motor imagery session alter imagined and actual movement durations: Potential implications for neurorehabilitation

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HIGHLIGHTS

- A prolonged motor imagery session induced mental fatigue.
- Mental fatigue induced an increase in both actual and imagined movements duration.
- The regular execution of actual movements counteracted the effect of mental fatigue.
- Motor imagery performance should be controlled for rehabilitation.

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ABSTRACT

Mental practice with motor imagery improves motor performance, for example reducing the duration of goal-directed movements. However, it is not known whether an experimental session involving prolonged sequences of motor imagery induces mental fatigue and alters motor and mental performances. In this study, participants imagined 100 point-to-point arm movements combined with actual pointing movements every 10 or 50 imagined movements. Participants reported a subjective feeling of mental fatigue after imagining 100 pointing movements. When participants performed actual movements every 50 imagined movements, the duration of both actual and imagined movements increased at the end of the protocol. On the contrary, no change in actual and imagined movement duration was observed when participants performed actual movements every 10 imagined movements. These results suggested that the repetition of many imagined movements induced mental fatigue and altered the mental simulation and the actual execution processes of the movement. However, the regular execution of actual movements seemed to counteract the negative effect of mental fatigue as both actual and imagined movement duration remained constant with actual trials inserted between mental rehearsals. We suggest that during training or rehabilitation programs, actual movements should be executed and/or imagined movement duration should be controlled to avoid the negative effects of mental fatigue on motor performance.

1. Introduction

Motor imagery is a dynamic state during which a subject mentally simulates body movements without actually executing them [1]. Motor imagery shares similar neural networks with those underlying actual movement execution [2,3]. Physical and imagined movements result in overlapping brain activations, including motor-related regions, the inferior and superior parietal lobules and the cerebellum [4,5]. Studies using techniques for mapping brain activity have provided evidence of a subliminal activation of the motor system during imagined actions [6], assuming that the CNS retains or attenuates the motor command before it reaches the neuromuscular level. The activation of the motor cortex during imagined movements has been confirmed using transcranial

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magnetic stimulation (TMS) studies that observed an increased evoked EMG response during motor imagery [7–9].

The repetitive activation of the motor system by mental practice enhances motor performance [10–12] and muscle strength [13–15]. Although one imagined training session is insufficient to obtain strength gains [16], motor actions such as grasping an object or drawing can be quickly improved by one session of mental practice [11,12,17]. It has been shown that mental practice improved the acquisition of spatio-temporal patterns [17] and enhanced movement velocity of both dominant and non-dominant arms [12,18]. Furthermore, the combination of mental and physical practice exacerbates the improvement in motor performances compared to physical practice alone [19–21], and improves the accuracy of motor imagery. Indeed, visual and kinesthetic information provided by physical practice refreshes the movement memory of the motor task [22,23].

However, prolonged mental practice also induced mental fatigue [16]. In a recent study, we showed that subjects perceived greater mental fatigue after a 20-min training session including 80 maximal imagined contractions (5-s contraction/10-s rest) of the elbow flexors. This subjective feeling of mental fatigue did not induce any alteration of the maximal voluntary torque, confirming previous results [24]. During mental practice of fine motor skills, Gentili et al. [12] observed that subjects started to develop fatigue and lose concentration after 60 trials of imagined pointing movements. As their goal was to analyze the improvement of motor performance following mental compared to physical practice, they limited their training to 60 trials. They only observed an improvement in performance in the earliest part of the mental training, followed by a stabilization of movement duration. Mental practice of fine motor skills seems to be more sensitive to training, as one training session is sufficient to observe an improvement of motor performance, but could be also more sensitive to mental fatigue. With a greater number of trials, one may expect that motor performance would be altered over the course of the trials. Furthermore, sensorimotor feedback seems to play a key role in learning and adaptation during mental practice [19]. Indeed, timing variability of imagined movements decreases when actual movements are regularly executed, suggesting that afferent information can be stored in working memory and used to recalibrate the imagined movements [19]. This finding suggests that the possible alteration of motor performance following prolonged mental practice could be prevented using the afferent feedback derived by executing actual movements.

With this in mind, the first aim of the present study was to analyze the influence of a prolonged motor imagery session, including 100 imagined trials of pointing, on the duration of goal-directed movements. The second aim was to analyze the influence of actual feedbacks on the duration of goal-directed movement during a prolonged motor imagery session. We hypothesized: (1) that mental fatigue induced by the repetition of imagined movements would increase actual and imagined movement durations and (2) that sensorimotor feedbacks (produced by actual movements) would counteract the negative effects of mental fatigue.

2. Materials and methods

2.1. Participants

In total, 44 healthy subjects (24 men and 20 women; mean age = 24.9 ± 5.7 (SD) years; mean weight = 66.5 ± 10.2 kg; mean height = 173.2 ± 7.3 cm) volunteered to participate in this study. Each participant participated in only one of the four experiments. All participants gave their written consent after being made aware of the experimental procedures. All had normal or corrected-to-normal vision, and none of them had any history of neurological disorders. Procedures were conducted in accordance with the Declaration of Helsinki, and were approved by the regional ethics committee of Burgundy.

2.2. Experimental design

2.2.1. Pre-tests and post-tests

During pre-tests, participants first completed a revised version of the Movement Imagery Questionnaire (MIQ-R, see Imagery ability and psychological state evaluations section) to evaluate their capacity to imagine movements. They were then familiarized with the actual and imagined pointing movements. They actually performed the pointing path used in the protocol (see Section 2.3.1) 10 times, followed by 10 imagined movements, 10 actual movements and 10 imagined movements. With 20 actual and 20 imagined pointing movements, we were confident that participants could obtain stable performances for the duration of actual and imagined movements [12]. After familiarization, participants completed the Brunel Mood Scale (BRUMS, see Imagery ability and psychological state evaluations section) and the Visual Analogue Scale (VAS). During post-tests, participants again completed the BRUMS and the VAS.

2.2.2. Experiment 1

Twelve participants (6 men and 6 women; mean age = 21.6 ± 1.8 years; mean weight = 63.0 ± 6.8 kg; mean height = 171.7 ± 6.8 cm) took part in this experiment. They performed a total of 100 imagined pointing movements (for a schematic representation, see Fig. 1). One actual pointing movement was performed at the beginning, after 50 imagined pointing movements and at the end of the protocol. Every imagined trial was separated by a 10-s rest period.

2.2.3. Control experiment

In this experiment, we controlled whether the mere passage of time could influence the duration of actual pointing movements. Ten participants (7 men and 3 women; mean age = 26.9 ± 3.1 years; mean weight = 71.2 ± 13.5 kg; mean height = 175.7 ± 8.3 cm) took part in this experiment. They sat resting at the table for 30 min, and performed one actual pointing movement at the beginning of the period, after 15 min, and a final one after 30 min (Fig. 1). The 30 min duration corresponded to the mean duration of the 100 imagined pointing movements performed in Experiment 1.

2.2.4. Experiment 2A

Twelve participants (6 men and 6 women; mean age = 23.9 ± 6.9 years; mean weight = 64.6 ± 8.6 kg; mean height = 171.7 ± 6.2 cm) took part in this experiment. They performed a total of 100 imagined pointing movements. Three actual pointing movements were performed at the beginning, after 50 imagined pointing movements and at the end of the protocol (Fig. 1). Every actual and imagined trial was separated by a 10-s rest period.

2.2.5. Experiment 2B

Ten participants (5 men and 5 women; mean age = 28.2 ± 6.9 years; mean weight = 68.3 ± 9.6 kg; mean height = 174.4 ± 7.5 cm) took part in this experiment. The protocol was the same as for Experiment 2A (100 imagined pointing movements with three actual movements at the beginning, after 50 imagined pointing movements and at the end), except that participants also performed one actual pointing movement every 10 imagined pointing movements (Fig. 1).