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Motor interference does not impair the memory consolidation of imagined movements

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ABSTRACT

The present study aimed to investigate whether an interference task might impact the sleep-dependent consolidation process of a mentally learned sequence of movements. Thirty-two participants were subjected to a first training session through motor imagery (MI) or physical practice (PP) of a finger sequence learning task. After 2 h, half of the participants were requested to perform a second interfering PP task (reversed finger sequence). All participants were finally re-tested following a night of sleep on the first finger sequence. The main findings revealed delayed performance gains following a night of sleep in the MI group, i.e. the interfering task did not alter the consolidation process, by contrast to the PP group. These results confirm that MI practice might result in less retroactive interference than PP, and further highlight the relevance of the first night of sleep for the consolidation process following MI practice. These data might thus contribute to determine in greater details the practical implications of mental training in motor learning and rehabilitation.

1. Introduction

Typically, the acquisition of a new motor skill relies on two distinct successive processes. A fast learning phase can be observed within session improvement, and then a slow latent time-dependent improvement occurs between sessions. This latter process is known as the consolidation phase (Brashers-Krug, Shadmehr, & Bizzi, 1996; Fischer, Hallschmid, Elsner, & Born, 2002; Karni & Sagi, 1993; Korman, Raz, Flash, & Karni, 2003; Korman et al., 2007; Walker, 2005), during which the memory trace becomes increasingly resistant to interferences resulting from competing or disrupting factors allowing the long-lasting storage of the skill (McGaugh, 2000). Stickgold and Walker (2007) argued that this term should refer to the automatic post-encoding processing occurring without intent or awareness, but not to those requiring conscious and behavioral rehearsal. Usually, the retroactive interference describes a case in which learning a second task interferes with the retention of another one. The concept of retroactive interference was introduced by Müller and Pilzecker (1900), who found that interpolating a new set of materials reduced the recall of an initial set of learned syllables. Lewis and Miles (1956) later demonstrated that retroactive interference might impede performance in the context of motor learning. Since these early studies, many authors found that there is no more interference when sufficient time (about 6 h) elapses between the two learning sessions (Karni et al., 1998; Korman et al., 2003; Krakauer & Shadmehr, 2006; Shadmehr & Brashers-Krug, 1997; Walker, 2005; Walker & Stickgold, 2004). Korman et al. (2007) further showed that retrograde behavioral interference at 2 h following training prevented the expression of delayed gains at 24 h post-training. In contrast, no interference was observed when the secondary learning sessions was performed at 8 h post-training. Song (2009) also argued that both the passage of time and sleep could stabilize learning from retroactive interference paradigms.

In the wealth of the motor learning literature, research dealing with retroactive interferences effects following mental practice is far less extensive. Motor imagery (MI) is a dynamic state during which one mentally simulates an overt action without any concomitant body movement (Jeannerod, 1994). There is now ample evidence that MI and physical practice (PP) share several parallel characteristics at the temporal, behavioral and neural levels (Guillot & Collet, 2008; Holmes & Collins, 2001; Munzert, Lorey, & Zentgraf, 2009; Murphy, Nordin, & Cumming, 2008). Interestingly, Wohldmann, Healy, and Bourne (2007) reported that MI might be as effective as PP to learn and maintain a new motor skill after a 3-month delay. In a second study, the same authors investigated the effect of a physical interference which was scheduled 1 and 2 weeks following the first learning phase (Wohldmann, Healy, & Bourne, 2008). The data revealed that the performance of

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the PP group was affected during the re-test, while the MI practice group showed perfect retention. These findings suggest that PP would strengthen an effector-dependent representation of the task, while MI might rather strengthen an effector-independent representation, and thus that MI might be considered a better training method in some cases.

Regarding motor skill acquisition processes, there is now compelling evidence that sleep contributes to the consolidation of motor sequence learning (Doyon et al., 2009; Karni, Tanne, Rubenstein, Askenasy, & Sagi, 1994; Walker, Brakefield, Hobson, & Stickgold, 2003). These findings support the role of sleep in the offline (re)processing of memories (Stickgold & Walker, 2007), and some authors have even suggested that PP should ideally be followed by sleep to ensure long-lasting storage of a newly acquired motor skill (Karni et al., 1998; Stickgold, LaTanya, & Hobson, 2000). So far, only two studies based on sleep data and motor skill learning literature have demonstrated that the consolidation processes remained effective following MI thereby supporting that a night of sleep after MI practice results in similar motor memory consolidation than following PP (Debarnot, Creveaux, Collet, Doyon, & Guillot, 2009a; Debarnot, Creveaux, Collet, Gemignani et al., 2009b). Overall, reporting delayed gains following a night of sleep might therefore present some advantages in determining whether learning a second motor task after having learned a first task, either through PP or MI, may interfere with the long-term consolidation of the first task. To date, however, no experimental data have combined these two approaches by examining the effect of retroactive interference on memory consolidation 2 h following MI practice after a night of sleep.

Based on the findings mentioned above, the present study was designed to investigate whether a physical interference task would alter the sleep-related motor memory consolidation following MI practice, as compared to that following PP. With reference to the experimental design used by Korman et al. (2007), the participants were first required to learn a new sequence of finger movements before mentally or physically practicing the same task during a training session. During the next stage (2 h later), they were subjected to the interference condition during which they physically performed a new finger sequence. Finally, their performance on the first motor sequence was re-tested after a night of sleep to test for possible delayed performance gains 24 h after the initial learning phase. In contrast to the participants assigned into the PP group, those engaged in MI practice were expected to develop an effector-independent representation of the task (Wohldmann et al., 2008). It was thus hypothesized that motor memory consolidation following MI would not be altered by the interference condition, hence resulting in delayed performance gains after a night of sleep.

2. Materials and methods

2.1. Participants

A total of 32 healthy volunteers aged between 20 and 35 years (mean age: 27 ± 3.5 years; 15 women) took part in this study. All were right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). They reported sleeping regularly between 7 and 9 h per night, and extreme evening- and morning-type individuals, as well as regular nappers and smokers, were excluded. None had any prior history of drug or alcohol abuse, neurological, psychiatric, or sleep disorders, and they were instructed to be drug, alcohol, and caffeine free for 24 h prior, as well as during the experiment. Musicians and professional typists were excluded to avoid participants with previous experience in finger tapping sequence tasks. This study was approved by the Research Ethics Committee of the University of Pisa, and all participants signed an informed consent form. The procedure was then explained and instructions regarding the motor task and questionnaires were given, while no information was provided about the objectives of the study or the variables of interest.

2.2. Design and apparatus

2.2.1. Sleep characteristics and MI abilities

All participants completed the Pittsburg Sleep Quality Index (Buysse, Reynolds, Monk, & Timothy, 1989) to assess sleep quality and quantity. This test was used to exclude individuals experiencing obvious disturbances during their sleep/wakefulness cycles, and to test for the participants' predisposition to benefit from the natural effects of sleep. Subjective measures of alertness and fatigue were also collected using the Stanford Sleepiness Scale (SSS, Hoddes, Dement, & Zarcone, 1972) during the experiment day. In regards to the individual MI abilities, the revised version of the Movement Imagery Questionnaire (MIQ-R, Hall & Martin, 1997) was used to measure the individual ability to form kinesthetic and visual mental images. The participants also filled out the revised version of the Vividness of Movement Imagery Questionnaire (VMIQ-2, Roberts, Callow, Hardy, Markland, & Bringer, 2008) to determine the vividness of MI, and the difference between their ability to use internal and external visual imagery.

2.3. Motor tasks

The experiment was scheduled at 9 am (±1 h). The participants were asked to learn a new sequence of eight finger movements (sequence A) using fingers 2–5 (3–2–5–2–4–5–3–4), until they were able to perform it explicitly from memory. The order of finger movements was pseudo-randomly selected such as each finger was used twice in a sequence. Following this introductory session, the pre-training test consisted of four blocks of PP lasting 30 s each. Participants tapped the sequence as fast and accurately as possible on a computer keyboard using the non-dominant hand, without any visual feedback. At the beginning of each block, as well as after completing each sequence, they were requested to push the space bar of the computer to allow recording of the motor sequence. At the end of the 30 s-period, the computer automatically indicated to the participants to remain motionless during the next 20 s, so that the pre-training session lasted 3 min. All key presses were recorded and averaged over the entire sequence using a home-made MATLAB-written routine. Then, the participants were randomly assigned into two groups ($n = 16$ in each group) which were subjected to either PP or MI of the same task. To ensure that enhanced performance would not depend upon the individual imagery abilities, we verified that both MIQ-R and VMIQ-2 scores did not significantly differ among the two groups. During MI practice, participants were required to imagine performing the finger sequence during 12 blocks of 30 s, which were separated by 20 s rest-periods, for a total duration of 9 min. The MI participants imagined performing the motor sequence learning task using a combination of internal visual and kinesthetic imagery. They rehearsed the finger sequence in a quiet room, without any environmental constraints. An imagery script was read to ensure that they received similar MI instructions. During MI, the participants were required to leave their left hand motionless, and were asked to keep their eyes open in order to read the instructions on the computer screen. They were requested to imagine performing the finger sequence at a pace that was similar to the pre-training session. To make sure that all participants would follow such guidelines, and to be able to record the duration of each MI sequence, they were asked to push the space bar with their right hand after imagining each motor sequence. Individual debriefings were scheduled