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Original article

Descriptive pilot study of vividness and temporal equivalence during motor imagery training after quadriplegia

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ABSTRACT

Background: Motor imagery (MI) training is often used to improve physical practice (PP), and the functional equivalence between imagined and practiced movements is widely considered essential for positive training outcomes.
Objective: We previously showed that a 5-week MI training program improved tenodesis grasp in individuals with C6–C7 quadriplegia. Here we investigated whether functional equivalence changed during the course of this training program.
Methods: In this descriptive pilot study, we retrospectively analyzed data for 6 individuals with C6–C7 quadriplegia (spinal cord injured [SCI]) and 6 healthy age-matched controls who trained for 5 weeks in visual and kinesthetic motor imagery or visualization of geometric shapes (controls). Before training, we assessed MI ability by using the Kinesthetic and Visual Imagery Questionnaire (KVIQ). We analyzed functional equivalence by vividness measured on a visual analog scale (0–100) and MI/PP time ratios computed from imagined and physically practiced movement durations measured during MI training. These analyses were re-run considering that half of the participants with quadriplegia were good imagers and the other half were poor imagers based on KVIQ scores. To investigate generalization of training effects, we analyzed MI/PP ratios for an untrained pointing task before (3 baseline measures), immediately after, and 2 months after training.
Results: During MI training, imagery vividness increased significantly. Only the good imagers evolved toward temporal equivalence during training. Good imagers were also the only participants who showed changes in temporal equivalence on the untrained pointing task.
Conclusion: This is the first study reporting improvement in functional equivalence during an MI training program that improved tenodesis grasp in individuals with C6–C7 quadriplegia. We recommend that clinical MI programs focus primarily on vividness and suggest that feedback about movement duration could potentially improve temporal equivalence, which could in turn lead to further improvement in PP.

1. Introduction

Quadriplegia is a severe condition consecutive to a cervical spinal cord injury (SCI) sparing the brain [1]. Depending on the level of injury, the resulting de-efferentation reduces the number of degrees of freedom, whereas de-afferentation impairs somatosensory and haptic inputs from the upper limb, both altering or preventing effective grasping movements [2]. Grasping is a primary rehabilitation aim [3] because regaining functional grasping greatly enhances independence [4]. Despite their injury, individuals with C6–C7 quadriplegia can learn to perform a passive grip (either lateral or palmar) by using the tenodesis grasp in which wrist extension leads to flexor tendon shortening [5,6].

Mental rehearsal of upper-limb movements seems to be a promising adjunct therapy to classical grasping rehabilitation programs [7,8]. Motor imagery (MI) is the construction of a mental representation from an internal perspective based on visual or kinesthetic information without simultaneous physical execution [9]. MI involves motor programming similar to that with physical

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practice (PP) but with inhibition of motor output at some level of the corticospinal flow [10]. Both PP and MI activate common brain regions [11], which suggest the engagement of similar internal models of action [12], and show similar movement durations (i.e., temporal equivalence [13]), which reflects the sharing of neural processes [14]. Activity in common neural circuits is thought to underlie improvements in motor performance observed after MI training in both healthy individuals [15] and those with SCI [7,8].

MI training programs aim to achieve functional equivalence: a vividness and duration of imagined movements as close as possible to that of physically practiced movements [14]. MI vividness refers to the clarity, brightness, or intensity of the mental reconstruction of the movement [16]. It is a marker of MI quality and is usually reported by participants on a visual analog scale (VAS) or questionnaires designed for specific populations [e.g., for individuals with SCI, the Kinesthetic and Visual Imagery Questionnaire (KVIQ, designed for people with motor impairments [17])]. Previous reports in healthy individuals have found high vividness scores related to greater performance improvement [18,19]. This result emphasizes the interest of using MI vividness as a marker of MI quality [20]. The temporal equivalence between MI and PP is also used to assess MI quality [21], and studies of healthy individuals and those with neurological impairments (including those with SCI) show that PP and MI have similar durations but lower vividness on the affected side [22,23]. In healthy individuals (athletes), MI training results in greater performance improvement in good imagers [15,18,19,25]. However, in individuals with quadriplegia, little is known about the functional equivalence between MI and PP, whether it can be modified by MI training, and if so, whether there is a relation between MI training effects and initial imagery capacity.

In a previous study of 6 individuals with C6–C7 quadriplegia, we showed that 5 weeks of MI training improved tenodesis grasp and induced plastic changes in the sensorimotor cortex [7]. These results suggest the potential interest of including MI in hand rehabilitation after quadriplegia, but several questions remain to be answered before investing in a large-scale study designed specifically to test the efficacy of MI training to improve grasping. Here, we present a descriptive pilot study in which we retrospectively analyzed MI data collected (but not included) in the above-mentioned kinematic/magnetoencephalography study. The aim of the current study was to ask whether MI training in individuals with quadriplegia alters functional equivalence, whether this depends on imagery ability, and whether MI training generalizes to a non-trained movement.

2. Methods

2.1. Study design and setting

Details of the initial longitudinal case-series study in which the data presented here were collected have been published elsewhere [7]. Briefly, the aim of the initial study was to examine tenodesis kinematics and brain plasticity after 5 weeks of MI training. It was part of a Hospital Clinical Research Program (HCRP-2008-541/142; ClinicalTrials.gov identifier NCT02860403). After gaining approval from the ethics committee of the university hospital (CPP 2009-051 B), all participants provided written informed consent in accordance with the Declaration of Helsinki.

The current descriptive pilot study retrospectively analyzed the effect of this MI training protocol on imagery vividness and the temporal equivalence (ratio of MI to PP duration) of the trained movements and on a complex, untrained pointing movement. Data were collected over 18 weeks in 3 different phases: a pre-training phase (weeks 1 to 5, before MI training began) during which temporal equivalence was measured while participants performed a complex pointing movement (untrained movement); 5 weeks of MI training (weeks 6 to 10, 3 sessions per week, each lasting 45 min) during which temporal equivalence and imagery vividness were measured for a single joint movement and reach-to-grasp movements (trained movements); and a post-training phase in which temporal equivalence was measured for the untrained pointing movement immediately after training and 8 weeks later (weeks 11 and 19, respectively). Pre- and post-training phases were identical for control participants and those with quadriplegia. However, 5 weeks of training in controls consisted of visualizing geometric shapes (3 sessions per week, each lasting 45 min) during which no measures of imagery performance were taken.

During the 18 weeks of the experiment, participants with C6–C7 quadriplegia continued their usual rehabilitation program, which consisted of twice daily 30-min sessions of physical therapy and daily 30-min session of occupational therapy, every weekday. This program consisted of strengthening and task-oriented practice including reach-to-grasp toward a range of objects with varied locations, orientations and sizes.

2.2. Population

Participants were 6 inpatients with chronic C6–C7 SCI [mean (SD) age 30.3 (8.2), ASIA Impairment Scale A–B] and 6 healthy control participants matched on age, sex, and handedness [mean (SD) age 28.3 (6.9)] [7]. Because extensor muscle strength reaches a plateau at about 6 months post-injury [26], we included only individuals at least 6 months after their injury. Five participants with quadriplegia were right-handed and one was left-handed according to the Edinburgh questionnaire [27]. All participants had 1) no history of traumatic brain injury associated with the SCI, 2) normal or corrected-to-normal vision, 3) normal control of the wrist extensor muscles (manual muscle test = 5/5 according to international standards [1]), 4) complete paralysis of finger flexors (0/5), 5) normal joint motion of the upper limb as measured by goniometry, and 6) no spasticity of the upper limb muscles (i.e., 0/4 on the Ashworth modified scale [28]). For each participant, we administered the KVIQ once during pre-training. We then averaged the scores for the 20 items of the KVIQ, and using a cut-off of 3.75/5 (proposed by McInnes et al. for stroke [29]), half of the participants with quadriplegia were classified as having good MI ability and the other half poor MI ability. Characteristics of participants with quadriplegia are summarized in Table 1.

2.3. Measure of temporal equivalence during a non-trained task

All participants imagined and physically practiced a pointing task 3 times before and 2 times after training. For this task, we positioned an A4 sheet flat on the table displaying 2 circles (diameters 30 and 84 mm, respectively; line thickness 1 mm) placed one inside the other with a 2-mm diameter solid circle placed at their center. Each circle had a mark at 3, 6, 9, and 12 o'clock (marker length 12 mm, line thickness 1 mm). All participants pointed with the index finger of their dominant arm. Starting from the center, participants touched each of the 4 marks on the small circle starting from 12 o'clock and turning clockwise. After each mark had been touched, they had to return to the center point (e.g., center–12–center–3–center–6–center–9). The participant then traced the circle clockwise with their index finger starting from the center then moving up to 12 and then traced the entire circle before returning to the center. The participant then repeated the same pointing and tracing sequence for the larger circle. We measured the total time for both imagined and physically practiced movements in order to compare their durations and to test temporal equivalence. For imagined

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