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ScienceDirect

Behavioural Brain Research 186 (2008) 273–283

BEHAVIOURAL BRAIN RESEARCH

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Research report

Mentally represented motor actions in normal aging II. The influence of the gravito-inertial context on the duration of overt and covert arm movements

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Received 6 April 2007; received in revised form 15 August 2007; accepted 20 August 2007
Available online 22 August 2007

Abstract

Here, we address the question of whether normal aging influences action representation by comparing the ability of 14 young (age: 23.6 ± 2.1 years) and 14 older (age: 70.1 ± 4.5 years) adults to mentally simulate arm movements under a varying dynamic context. We conducted two experiments in which we experimentally manipulated the gravity and inertial components of arm dynamics: (i) unloaded and loaded vertical arm movements, rotation around the shoulder joint, (ii) unloaded and loaded horizontal arm movements, rotations around the shoulder and elbow joints, in two directions (inertial anisotropy phenomenon). The main findings indicated that imagery ability was equivalent between the two groups of age for the unloaded arm movements, but better for the young than the older group, for the loaded arm movements. For the horizontal movements, we found better imagery ability for the young than the older adults for both movement directions and loads. Finally, young and old adults showed low (<8%)-temporal variability for both overt and covert arm movements in all conditions. Our findings showed a specific decline of action representation in the aging brain and suggest that internal models of action become imprecise with advance in age. This is not exact to say that there is a severe impairment of motor prediction in old adults as they can mentally represent their arm movements with high-temporal consistency. Finally, we propose that motor imagery could be used as a therapeutic tool for motor rehabilitation in aged adults.
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Keywords: Motor imagery; Aging; Arm movement; Motor prediction; Internal models; Plasticity

1. Introduction

Motor imagery is a cognitive process during which subjects internally simulate a movement (first-person perspective) without actually performing it. This conscious mental state can be used to investigate action representation and sensorimotor prediction [20]. Internal movement simulation or covert action, share several neurocognitive correlates with movement execution or overt action. For instance, the exploration of brain activity has revealed that similar neural structures are involved in covert and overt motor actions. Although this overlap is not perfect, the parietal cortex, the supplementary motor area, the premotor, prefrontal and primary motor cortices, the cerebellum and the basal ganglia are activated during executed and imagined movements involving several body parts [6,12,16,21,44]. Similarities between overt and covert motor actions have also been described at the physiological level. For example, autonomic activation increases proportionally to the mental effort produced by subjects during imagined movements [3,10,34,38]. Furthermore, experiments have provided evidence that motor imagery training enhances muscular force [50,51] and improves motor performance [15,47]. Finally, psychophysical investigations have demonstrated that movement execution and its mental replication rely on similar spatiotemporal and biomechanical constraints and follow the same laws of movement control [9,27].

Previous investigations have also reported that gravito-inertial forces, which dramatically influence arm dynamics and kinematics, are well incorporated during the mental replication of 3D arm movements [14,30–32]. In addition, the mental prediction of gravito-inertial forces during motor imagery practice significantly improves arm motor performance in young adults [15]. However, the internal simulation of skilful arm movements, which are under the influence of gravito-inertial forces,

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0166-4328/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.bbr.2007.08.018

must be a great challenge for older adults as normal aging modifies cognitive abilities [11,26,33,37] and affects sensorimotor control [4,23,24,40]. In this context, one could wonder if motor representations in older adults would be as accurate as they are in young adults. Precisely, considering that the temporal invariance between executed and imagined movements suggests similar motor representations (internal model) for an action, whether it is executed or imagined, one could be sceptical whether older adults would preserve temporal similarities between imagined and executed movements in a varying gravito-inertial context. In previous investigations, using a Fitts' law motor paradigm, we found temporal differences between executed and imagined arm movements in older adults [41]. These findings suggest weakness in their ability to represent motor actions requiring high-spatiotemporal control. In the present study, we anticipated similar behaviour for dynamic motor representations. We proposed two experiments in which we experimentally manipulated the gravity and inertial components of arm dynamics and we examined how they influenced the duration of executed and imagined arm movements in aged adults.

2. Experiment 1

Mechanically, the dynamics of arm movements are largely related to the inertial and gravity forces. In the first experiment, our primary intention was to understand how aged adults integrate inertial and gravity components of motion dynamics when they mentally represent arm movements. We considered that the temporal analysis of covert and overt arm movements could provide valuable information about the integration of motion dynamics into the action representation. Notably, similar temporal features between executed and imagined movements would suggest that the same internal model, which integrates the dynamic context of the action, governs both modalities (executed and imagined). This is valid for young adults. Indeed, previous results from our laboratory indicate that young adults accurately integrate gravito-inertial forces during the mental replication of 3D arm movements [14,30–32]. The question is open, however, for the aged adults. Here, we simplified the influence of gravito-inertial forces in arm motion by examining relatively simple movements, i.e. single joint vertical arm movements (rotation around the shoulder joint). The gravity and inertial components of arm dynamics were respectively manipulated by performing arm movements in the sagittal plane and by adding a load on the hand. In view of the fact that mental and motor processes become slower with age [39,43] we hypothesised that action representation under dynamic conditions in aged adults will not be as accurate as it is in young adults.

2.1. Materials and methods

2.1.1. Participants

Twenty-eight, right-handed, adults participated in the present study after giving their consent. Handedness was determined by means of the Edinburgh Handedness inventory [29]. In addition, participants performed multiple behavioural tasks (writing, catching, grasping and throwing) which also confirmed right-hand dominance. Participants were divided in two different groups according to their age: (i) the young group (8 males and 6 females; mean age: 23.6 ± 2.1 years) and (ii) the old group (6 males and 8 females; mean age: 70.1 ± 4.5 years). All participants were in good health, with normal or corrected vision and did not present any nervous, muscular or cognitive disorders. The older adult participants were all retired, had a regular physical activity (~1.5 h, 2 days per week, approved by a medical doctor) and at least one daily cognitive activity (reading newspapers, crosswords or literature). They also had cognitive evaluation by means of the *mini mental state examination* test (all scores > 28). All participants received complete information about the experimental procedures, but none of them was informed of the aim of the experiment. A local ethics committee approved the experimental protocol which was carried out in agreement with legal requirements and international norms (Declaration of Helsinki, 1964).

2.1.2. Motor tasks and experimental procedure

The experiment took place in a small room (5 m × 4 m), which was sound-attenuated, temperature regulated ($22 \pm 2\,^{\circ}$C) and illuminated with homogeneous white light. The participants were seated on an armless and adjustable chair placed at knee height. A back support on the chair was used to set their trunk in the vertical position. They were requested to execute (overt action) and to mentally simulate (covert action) arm movements in the sagittal plane using their dominant (D, right) arm in two different loading conditions: (i) arm free, i.e. without additional load (NL), (ii) arm holding a load (L), i.e. a mass grasped by the palm of the hand. Arm movements mobilized only the shoulder joint. The elbow joint was fully extended and the semi-pronated hand was aligned with the upper arm and forearm during the whole duration of the movement (Fig. 1A). We visually verified during the whole experiment that arm movements mobilized only the shoulder joint. The movement started with the arm aligned with the vertical axis (hand downwards) and consisted of six subsequent reversal movements, each of them involving an angular displacement of 90°: upward (until the arm was aligned with the antero-posterior axis), downward (until the arm was aligned with the vertical axis), upward, downward, upward and downward (Fig. 1B). In order to facilitate the participants in the accomplishment of the executed and the imagined arm movements, two pairs of targets (placed in the sagittal plane and aligned with their right arm) indicated the start- and the end-point of the movement. Participants executed or mentally simulated the arm movements at a natural speed, without further specific instructions concerning movement duration or velocity. However, we gave particular attention to the instructions concerning the mental simulation of the motor task: subjects were instructed to feel themselves executing the movement (internal or motor imagery) rather than simply watch themselves performing it (external or visual imagery). Eye movements were tolerated in both executed and imagined movements in order to facilitate the fixation of the targets during the six subsequent reversal arm movements. On the other hand, we did not allow head movements. All participants executed and imagined arm movements by keeping their head motionless. In the L condition, participants held the load with the right hand during the executed as during the imagined movements. However, in the imagined condition the arm remained immobile and aligned with the vertical axis (0°). After the achievement of the experimental protocol, none of the participants reported difficulties to internally simulate arm movements.

Grasping a load in the hand significantly changes the dynamics of arm motion by varying both inertia and gravity torques, which can be calculated according to dynamical equations and anthropometric data [46]:

$$T = \mathrm{IT} + \mathrm{GT} \quad \text{(Torque around the shoulder joint)}$$

$$\mathrm{IT} = Ia \quad \text{(Inertial torque)}$$

$$\mathrm{GT} = mgr \quad \text{(Gravity torque)}$$

I, is the arm inertia around the shoulder joint, a, the shoulder angular acceleration, m, the mass of the arm, g the constant acceleration of gravity and r is the perpendicular distance from the arm center of mass to the vertical axis.

In the current experiment, we individually adapted the magnitude of the additional load (L condition) in order to increase with respect to the NL condition by 50% the maximum gravity torque around the shoulder joint (calculated when the arm was aligned with the horizontal axis). For example, in the NL condition, for a participant whose body weight and arm length are respectively 67 kg and

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