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Research report

When I am (almost) 64: The effect of normal ageing on implicit motor imagery in *young elderlies*

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HIGHLIGHTS

- Implicit motor imagery (IMI) depends on premotor/parietal and occipital cortices.
- We compared the IMI skills and associated brain activations of young and elderly subjects.
- Healthy elderlies in their sixties had qualitatively preserved implicit motor imagery skills.
- Their juvenile performance was accompanied by stronger activation of visual cortices.
- These findings encourage a controlled use of motor imagery for rehabilitation in elderlies.

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ABSTRACT

Motor imagery (M.I.) is a cognitive process in which movements are mentally evoked without overt actions. Behavioral and fMRI studies show a decline of explicit M.I. ability (e.g., the mental rehearsal of finger oppositions) with normal ageing: this decline is accompanied by the recruitment of additional cortical networks.

However, none of these studies investigated behavioral and the related fMRI ageing modifications in implicit M.I. tasks, like the hand laterality task (HLT).

To address this issue, we performed a behavioral and fMRI study: 27 younger subjects (mean age: 31 years) and 29 older subjects (mean age: 61 years) underwent two event-related design fMRI experiments. In the HLT, participants were asked to decide whether a hand rotated at different angles was a left or right hand. To test the specificity of any age related difference in the HLT, we used a letter rotation task as a control experiment: here subjects had to decide whether rotated letters were presented in a standard or a mirror orientation.

We did not find any group difference in either behavioral task; however, we found significant additional neural activation in the elderly group in occipito-temporal regions: these differences were stronger for the HLT rather than for the LRT with group by task interactions effects in right occipital cortices.

We interpret these results as evidence of compensatory processes associated with ageing that permit a behavioral performance comparable to that of younger subjects. This process appears to be more marked when the task specifically involves motor representations, even when these are implicitly evoked.

1. Introduction

1.1. Motor imagery as a window on motor representations

Motor imagery (M.I.) is a mental state during which movements are mentally evoked and rehearsed without overt actions [48].

A functional equivalence between M.I. and real movement execution is suggested by several lines of evidence: for example, the isochronism of the physical and mental performances of the same

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action, (see for example Decety et al., 1989, and the impact of biomechanical constraints on M.I. performance [80,70]. Moreover, TMS and EMG evidence show a pre-activation of motor pathways during motor imagery tasks [54,77], while a partial overlapping of the neural networks activated during motor execution and imagination was revealed by PET and fMRI (see for example [39]).

Motor imagery is also being used as a Trojan horse to explore the organization of the motor system where the presence of an explicit motor outflow might be not desirable (e.g., in clinical conditions characterized by involuntary movements like, Gilles de la Tourette Syndrome – see Refs. [97,98] or, in combination with fMRI, as a tool to detect residual awareness in patients unable to do so, such as, for example, patients with a diagnosis of vegetative state [66].

An exciting new exploitation of motor imagery activity is being implemented in the area of neuroprosthetics: it has been shown that neural signals from posterior parietal cortex, decoded during a motor imagery behavior, can govern a robotic limb in a tetraplegic patient and encode complex aspects of motor planning, including motor goals [1] while signals decoded from motor cortex would encode continuous control signals as those needed for reaching tasks [43,42].

All this evidence is a clear vindication of the fact that during motor imagery subjects are capable of recruiting motoric representations and these findings provide the rationale for using M.I. in a variety of basic research and clinical domains for the study of motor neurocognition as well as in rehabilitation programs (for a review see Ref. [60].

For example, M.I. trainings have been used in motor rehabilitation after stroke with variable fortunes [93,67,47,46,27], after brain injury [55,78], in movement disorders [9,40], but also as a complementary treatment of non-neurological patients to boost motor recovery after orthopedic surgery [14,53].

M.I. has been also used to reinforce motor skills learning in healthy subjects [52,35], including athletes [59].

1.2. Explicit and implicit motor imagery

The action simulation involved in M.I. can be triggered explicitly or an implicitly, depending on the instructions and task characteristics.

In explicit M.I., subjects are directly asked to imagine themselves executing the required actions (e.g., "Imagine flexing and extending your fingers" [28] and to focus on kinesthetic bodily sensation by taking a first-person egocentric perspective.

Explicit M.I. skills are indirectly investigated with self-report questionnaires or mental chronometry paradigms; the isochronism of executed and imagined movements is taken as evidence that explicit M.I. has motoric components [15].

On the other hand, in implicit tasks the M.I. process may be triggered without explicit reference to the concept of M.I. during "prospective action judgments" [49], as in the Grip Selection Task, where subjects are asked to judge whether a tool is oriented conveniently for being grasped with the right or with the left hand [81,50,19]; another example of an implicit M.I. task is the hand laterality task (HLT), where subjects are asked to decide whether hands portrayed in a picture (rotated at different angles) are the left or right one. It is believed that during this task subjects unconsciously simulate a mental rotation of their own hand to match the position of the depicted hand stimulus, hence producing "motorically driven perceptual decisions" [69]. The contribution of a motoric component during the HLT is supported by several PET and fMRI studies showing the involvement of the premotor cortices (the lateral premotor cortex and the SMA), of posterior parietal cortices (the superior parietal lobule and intraparietal sulcus) and the cerebellum [7,71,51,88,92,81,21,29,95].

The motoric nature of implicit M.I. is also demonstrated by studies on patients with severe motor impairment: [17,16] investigated the role of descending motor pathways on mental simulation of actions using the HLT in locked-in patients; in the first study (2008) they showed a specific impairment only in HLT, associated with the absence of visuo-motor compatibility or biomechanical effects, while normal performance was recorded in the mental rotation of external objects [17,16]. More recently, Fiori et al. [30] replicated these findings in patients with amyotrophic lateral sclerosis.

The involvement of motor representations seems to be view-dependent, with greater engagement of kinesthetic strategies and larger enrolment of motor cortical networks when hands are displayed in a palm-view perspective [86,85,6,87,95].

Because of the implicit nature of the mechanisms whereby motor representations are evoked by tasks like the HLT, a specific potential use in rehabilitation could be envisaged for clinical conditions like hemiplegia accompanied by anosognosia in which patient cooperation with explicit strategies may be lacking in spite of some sparing of cortical motor regions and their function [34].

1.3. Motor imagery in the life cycle: behavioral and fMRI findings

There is also a well-documented decline or reshaping of M.I. as a result of normal ageing [74,83,75,84,79,56,73,96]. Malouin et al. [56] reported age-related quality changes in explicit M.I. vividness, associated with an age-related decline in visuo-spatial and kinesthetic working memory. Chronometric studies revealed a loss of temporal congruence between motor execution and explicit M.I., especially for unusual and constrained movements [74,83,75,84,73,96]. These changes were accompanied by neurofunctional changes, such as the over-recruitment of occipito-temporal areas, suggesting the adoption of a complementary strategy based on visual imagery to compensate for M.I. decline [96].

To date, only a few behavioral studies investigated the influence of ageing on implicit M.I. processes, the focus of our investigation here. Saimpont et al. [79], for example, reported a decline in the ability to implicitly simulate hands movements in elderly subjects, with longer RTs and lower accuracy, especially for the non-dominant hand and for stimuli presented in awkward positions with reference to the biomechanical constraints imposed by the stimuli. Devlin and Wilson [25] found similar results, showing a decline in the elderly's performance in the HLT but also in a whole-body mental rotation task: they speculate that age-related changes in M.I. could be due to disruption of body schema.

A combination of the classical HLT in an egocentric reference frame and the same task in an allocentric-reference frame has been used in a recent study by De Simone et al. [23] to compare multisensory, sensory-motor, and visual aspects of implicit M.I. in elderly and younger people. During both tasks subjects were shown pictures of rotated hands with a red dot depicted on the extremity of the little finger or ring finger, or the index finger or thumb. In the egocentric laterality task they were asked to report whether the presented hand was a right or a left one, while in the allocentric task subjects were asked to report whether the dot was on the left or on the right side of the hand as it would be seen in the upright position [23]. They showed that elderly participants were less accurate and slower for biomechanically awkward hand postures only when performing the HLT in an egocentric-reference frame; they concluded that ageing is associated with a specific degradation of the sensory-motor mechanisms necessary to perform complex effector-centered mental transformations [23].

It is worth noting that the aforementioned studies are based on elderly subjects on average in their mid-seventies. It remains unknown what happens in *younger* elderlies, one and a half decades