Eur Arch Psychiatry Clin Neurosci (1990) 240:39–43

European Archives of Psychiatry and Clinical Neuroscience

Effect of Brain and Spinal Cord Injuries on Motor Imagery

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Received January 20, 1990

Summary. The timing of mentally executed movements was measured in ten patients with hemiplegia, tetraplegia and paraplegia. In hemiplegic patients a significant difference in mental duration times was found between the paralysed and the normal "represented limb". The paralysed limb was mentally much slower than the healthy one. In contrast, movement times in tetraplegic and paraplegic patients did not differ from those in normal subjects. All patients reported a sensation of subjective effort accompanying the execution of the mental tasks. These observations are compatible with an outflow processing underlying motor imagery.

Key words: Cognitive-motor processes – Motor imagery – Sensation of effort – Hemiplegia – Tetraplegia – Paraplegia

Introduction

Theorists in motor behaviour have conceptualized action from an information processing approach. There is common agreement that motor acts are centrally represented, and, like other representations, are stored, modified, and may be retrieved through specific cognitive processing (Stelmach and Hughes 1984). Furthermore, it is generally thought that cognitive processes and overt behaviour are intimately related. One approach for investigating the interaction between cognitive and motor processes is to study motor imagery (internal representation of a motor act: Denis 1985).

Many experiments have demonstrated that mental training may have a positive effect on motor performance as a skill facilitator (for a review see Feltz and Landers 1984). Mental training refers to the systematically repeated, inner rehearsal of a movement in the absence of any gross muscular movements. Such a procedure is widely used in the training of high-level athletics. Thus, imagery of movements (motor imagery: MI) is investigated both in the field of cognitive psychology and in motor learning. In contrast, MI has not to our knowledge been studied or reported in clinical neuropsychology in patients with injuries at different levels of the motor system.

A variety of processes may be involved in MI, mainly visual and kinaesthetic (Denis 1989). Their selective participation seems to depend on the instructions given to the subjects, which may stress either visualization of the movement (third-person perspective) or its kinaesthetic feeling (first-person perspective). Furthermore, when a subject imagines in the *first-person perspective* and experiences the sensations arising in the actual movement, he/she can evoke a kinaesthetic "image" of it. This image is dynamic and it has been found that the timing of mentally executed movements is almost identical to the timing of actual movements and very stable in a given subject from trial to trial (Decety et al. 1989b). In normal right-handed subjects required to write (actually) or to imagine to write (mentally) a given sentence, or to draw a Necker's cube, either with the right or with the left hand, it was found that, in the writing task, the mental left hand was slower than the mental right hand to the same degree as the actual left hand and the actual right hand. However, the right-left duration differences were only a tendency in the drawing task, which requires less graphic skill than does the writing and is also supposed to be more controlled by the right hemisphere (Decety and Michel 1989). This suggests that the duration time in both mental and actual conditions is determined, to a great extent, by both hemispheric specialization and manual proficiency.

Studies reported by Jacobson in 1932 showed that some myoelectric activity (EMG) can be measured in the muscles involved by the imagery task. A recent study has confirmed this finding and indicated that the EMG activity during MI clearly shows a task-specific frequency distribution (Wehner et al. 1984). On the basis of these

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results, we have developed a neuropsychological hypothesis which seeks to explain MI in terms of neural structures underlying the information processes involved (Decety and Ingvar 1990). This hypothesis assumes that during MI the motor programme, considered as a representation of an action in which parameters for the execution are represented (see Jeannerod 1988), might be "read off". As Pickenhain (1984) stated, during MI the efferent inpulses of the complex motor programme reach all parts of the central nervous system which serve as sub-programme effectors of the whole process of realization. At the same time the real movement is being inhibited. The triggering of the programme may thus occur during MI as well as during actual practice. This would explain the relative equivalence in timing between actual and mental motor performance. The elements of those mechanisms may thus be activated both in MI and in actual behaviour (MacKay 1980; Kohl and Roenker 1983). Moreover, measurements of regional cerebral blood flow (rCBF) during MI have shown the activation of the supplementary motor area, the thalamus, the neostriatum and the cerebellum (Roland et al. 1980, 1985, 1987; Decety et al. 1988, 1989a). There is thus evidence that MI and actual motor behaviour share, to some extent, the same underlying neural mechanisms.

If one accepts that the timing of mentally executed actions can be used as a measure of the underlying neural motor programming processes in MI, then a relevant issue would be to measure the timing of MI in patients with brain injuries specifically affecting the motor system, but who have no deficits in their ability for visual imagery and in their speech funciton. In addition, while it is generally accepted that certain effector and receptor mechanisms may subserve the conscious appreciation of movement (Kelso and Wallace 1978), one can expect a report about a sensation of effort accompanying MI, as has been observed by Grandevia (1982) in muscular paralysis when patients attempted to move. Therefore, hemiplegic, tetraplegic and paraplegic patients were investigated.

Patients and methods

The timing of mentally executed movements was measured in three different tasks: signing, drawing and hopping. Patients were required to perform the tasks in two conditions: mentally and, when it was possible, actually. The movement time and the verbal reports were recorded.

In order to avoid the effects of severe neuropsychological deficits, ten neurological patients (6 males and 4 females) were selected on the following criteria: unilateral lesions on CT, absence of aphasic, apraxic and verbal comprehension impairments and a good educational level (i.e. high school completed). All patients volunteered to participate in the present study. The average age was 28 years (SD 9.2). All patients were right-handed (LQ > 90) according to the Edinburgh handedness inventory (Oldfield 1971).

The group consisted of three patients with right-sided hemiplegia (cases 1–3), three patients with left-sided hemiplegia (cases 4–6), two patients with paraplegia (cases 7, 8) and two patients with tetraplegia (cases 9, 10) (see Table 1).

The selected patients were trained in mental imagery prior to the experimental session and they were tested as to their visual imagery ability. None of them showed an impairment in visual orientation or in visual scanning, as shown in particular with Farah's test (1985) in which patients had to sort letters containing straight or curved lines.

Table 1. Patient data

Cases	Sex	Age (years)	Motor disturbance	Clinical history
1	F	17	Right HP	CI October 1986
2	M	28	Right HP	CI September 1987
3	M	21	Right HP	TAC July 1987
4	F	28	Left HP	VM October 1986
5	F	47	Left HP	CI March 1987
6	F	33	Left HP	CI October 1987
7	M	40	PP	TA July 1987
8	M	30	PP	TA March 1987
9	M	20	TP	TA June 1986
10	M	23	TP	TA August 1987

HP, Hemiplegia; PP, paraplegia; TP, tetraplegia; CI, cerebral infarction; TA, traumatic accident; VM, vascular malformation

Cases 1 and 2 had initial transient and regressive phasic deficits, which resolved completely. Cases 3–5 were pure motor hemiplegics. Case 6 initially had a left visuo-spatial neglect, which rapidly regressed, although a sensitive extinction has remained on the left side associated with a visual extinction in the double stimulation condition

During the experimental session, patients were asked to perform actually or mentally three different motor tasks: (1) writing their signature, (2) drawing a Necker's cube, and (3) hopping on one leg. Tasks 1 and 2 were performed either with the right or the left hand (when possible); task 3 was only performed mentally with either the right or the left leg, since none of the patients could actually perform the tasks.

Verbal instructions were given for each mental trial in the same presentation order, e.g. *"Close your eyes, imagine that you are going to perform the drawing task. You have a pencil in your right hand, try to feel it, and, when you hear the signal* (sound), *start drawing the cube in your mind."*

Movement times were measured with a chronometer switched on/off by the experimenter. In the actual condition, the time was taken from the first contact of the pen on the sheet of paper until the last contact. In the mental condition, patients were required to close their eyes and start the task when they heard an auditory signal and to open their eyes at the end of the task. The time was recorded between the auditory signal (which was synchronized with the chronometer) and the patient's eyes opening. In the hopping task, the patients were instructed to visualize mentally a square (1.5 × 1.5 m) drawn on the ground and imagine standing on either the right or the left leg, then start hopping around the square at a given signal.

In each of the three tasks (signing, drawing, hopping) and two conditions (actual/mental) 15 trials were performed. Conditions and tasks were randomized in order to avoid a block effect. Measurements were made for each patient at two different times separated by an interval of a week, in order to improve reliability.

Results

Statistical significance of movement times was analysed by paired *t*-tests (*df* 14) within each patient according to the hand or leg used, between actual and mental conditions and between right and left limb measurements.

Table 2. Coefficients of variation (CV) and standard deviations (SD) in the actual and mental *signing task* (mean percent value in seconds)

	Actual		Mental	
	CV	SD	CV	SD
Right hand	7.52	(1.83)	7.81	(0.64)
Left hand	7.06	(1.79)	6.65	(1.11)

Table 3. Coefficients of variation (CV) and standard deviations (SD) in the actual and mental *drawing task* (mean percent value in seconds)

	Actual		Mental	
	CV	SD	CV	SD
Right hand	6.47	(0.93)	7.04	(0.68)
Left hand	6.01	(0.62)	6.65	(1.07)

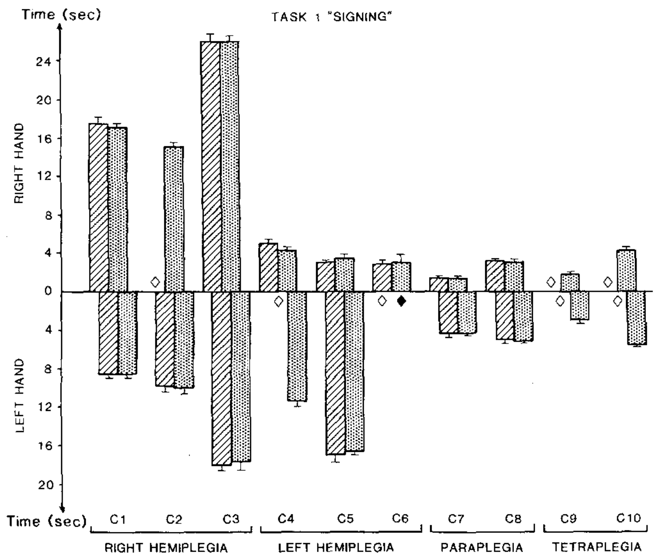

Fig. 1. Mean movement times and standard deviation in seconds in the signing task. *AMT*, Actual movement time (▨) *MMT*, mental movement time (▤); ◊ AMT impossible; ♦ MMT impossible

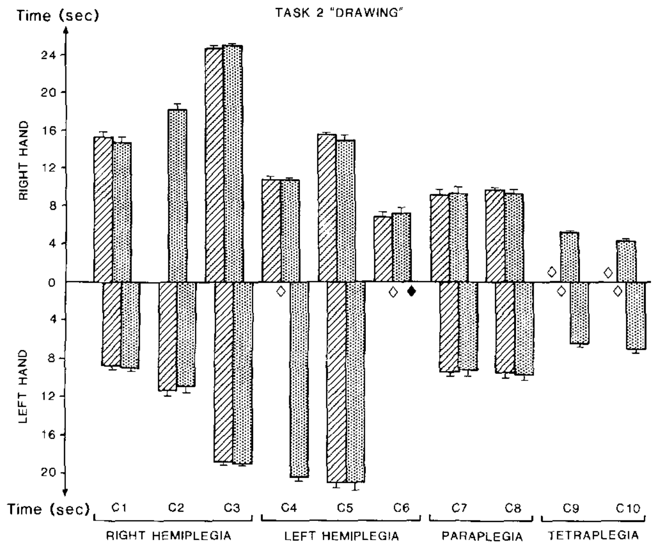

Fig. 2. Mean movement times and standard deviation in seconds in the drawing task. *AMT*, Actual movement time; *MMT*, mental movement time. (For explanation, see figure legend 1)

Signing

The intra-patient movement time variability within each condition appeared to be very small, as is illustrated in Table 2.

The time required to perform the movement mentally did not significantly differ from the time required to actually perform the movement ($P > 0.10$), but was dependent on whether the movement concerned the right or the left hand. In patients with right hemiplegia (C1–3), the right-hand movement times in both conditions (actual/mental) were significantly different and higher than left-hand movement times ($P < 0.001$). Likewise, for the patients with left hemiplegia (C4–7), the left hand produced in both conditions a significant difference ($P < 0.001$). The inability of cases 2–4 to perform the actual movement was due to persistance of the motor deficit. Nevertheless, they could perform the task mentally.

One patient with left hemiplegia (C6) was not able to perform the task with his left hand in both conditions.

The paraplegic and tetraplegic patients showed a significant difference between the right and left hand, corresponding to their motor proficiency handedness ($P <$ 0.001), as has been found in normal subjects (Decety and Michel 1989).

Drawing

The intra-subject variability was very small, as shown in Table 3.

Mental movement times appeared similar to actual movement times for both hands ($P > 0.10$). The patients with right hemiplegia showed significant differences between the right and the left hand in both conditions ($P <$ 0.001), the right hand always being slower than the left. In patients with left hemiplegia, the left-hand movement times were significantly longer than the right-hand movement times ($P < 0.001$).

Patient C6 with left hemiplegia was not able to perform the mental task with his left hand in any of the conditions. The paraplegics and tetraplegics showed a significant difference between the right and the left hand, corresponding to their handedness ($P < 0.001$).

Hopping

Since none of the patients were capable of standing up without help, the hopping task was only performed mentally. Again, the intra-subject variability was very small (Table 4).

The right hemiplegic patients were significantly slower when imagining hopping on their right than hopping on

Table 4. Coefficients of variation (CV) and standard deviations (SD) in the mental *hopping task* (mean percent value in seconds)

	Actual	
	CV	SD
Right hand	5.21	(1.39)
Left hand	5.89	(1.15)

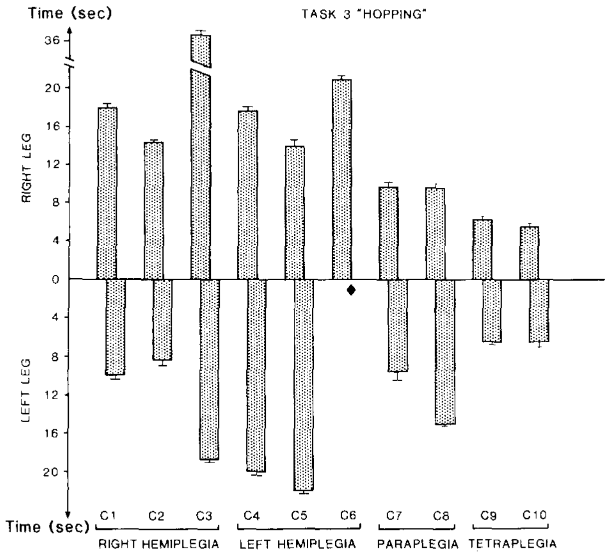

Fig. 3. Mean movement times and standard deviation in seconds in the hopping task. *MMT*, Mental movement time. (For explanation, see figure legend 1)

their left leg ($P < 0.0001$). The opposite was observed in left hemiplegic patients, who were slower when hopping on their left leg.

Again patient C6 did not perform the mental task when the left leg was involved.

Paraplegic and tetraplegic patients showed a significant difference in mental movement times between the right and the left leg, which corrsponded to their dominant foot.

Verbal reports

After each session the patients were interviewed. Hemiplegic patients reported spontaneously that they had a sensation of effort while they performed the mental tasks, and that it required more effort to imagine a movement with the paralysed limb. Some of these patients also reported that they had a sense of falling several times when they were hopping mentally. Patient C6 reported an inability to imagine any movements with his left hand and left leg. The reason for this inability could be due to a more global disorganization of sensorimotor integration, although the clinical recovery was comparable with the other patients reported in this study. The paraplegic and tetraplegic patients also reported a sensation of effort accompanying the mental tasks.

Discussion

If one accepts that the length of time required to imagine (or to simulate mentally) a motor act is an indirect indication of the mechanisms involvement in MI, then the following observations might be made.

Patients with supratentorial motor disturbance may also have an impairment in their cognitive ability to imagine a motor act, as shown by the duration times for the tasks involving the paralysed limb. Patients with peripheral lesions, however, were not different from the normal subjects (Decety and Michel 1989). Hence, high level motor processes, presumably cortically localized, appear to interact with the information processing units which underlie the mental representation of motor behaviour.

The other main finding is that MI was accompanied by a sensation of effort, as in voluntary contraction of skeletal muscles (see Gandevia 1987). This was observed in all patients. Our study thus confirms and supports the finding of Gandevia (1982) that sensations of effort persist in patients with spinal transection, indicating that a signal can be generated centrally and that it can arise without either an afferent input from a paralysed limb or a recurrent signal from spinal motorneurons.

Both the temporal feature of actions mentally represented and verbal reports of a sensation of efforts lend support to an outflow interpretation of information processes underlying MI. It is therefore of interest to relate the present result to Gandevia's studies (1982, 1987) on central mechanisms responsible for the sense of effort in hemiplegia.

It has also been hypothesized that timing mechanisms underlying motor and perceptual processes involve the same "internal clock" (Keele et al. 1985). One may suggest, on the basis of our preliminary results, that MI may involve the same clock mechanism as the actual motor behaviour. The "mental slowing down" observed in hemiplegia does not necessarily imply disorder in the clock, since the intra-patient variability within each task was small. However, there might be an impairment in the central implementation of the clock. Further study is warranted to investigate this hypothesis.

Finally, one would like to suggest that MI might also be helpful in physiotherapy as a method for facilitating recovery in situations where physical practice is difficult or precluded by paralysis circumstances. One can assume that improvement might occur, although its evaluation is difficult. MI could be seen as a strategy to set "mental goals" and to generate an internal dynamic representation of the intended movement. This may enhance the flow of information processing which precedes the execution of the movement.

Acknowledgements. The authors thank S. Stone-Elander (Karolinska Institute, Stockholm) and D.H. Ingvar (University of Lund) for critically reading an earlier draft of this paper.

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