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Mental rotation in schizophrenia

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Abstract

Motor imagery provides a direct insight into action representations. The aim of the present study was to investigate the level of impairment of action monitoring in schizophrenia by evaluating the performance of schizophrenic patients on mental rotation tasks. We raised the following questions: (1) Are schizophrenic patients impaired in motor imagery both at the explicit and at the implicit level? (2) Are body parts more difficult for them to mentally rotate than objects? (3) Is there any link between the performance and the hallucinating symptom profile? The schizophrenic patients ($n = 13$) displayed the same pattern of performance as the control subjects ($n = 13$). More particularly, schizophrenic patients' reaction time varied as a function of the angular disparity of the stimuli. On the other hand, they were significantly slower and less accurate. Interestingly, patients suffering from hallucinations made significantly more errors than non-hallucinatory patients. We discussed these latter results in terms of deficit of the forward model. We emphasized the necessity to distinguish different levels of action, more or less impaired in schizophrenia.

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1. Introduction

Several authors have suggested that the main underlying cognitive deficit in schizophrenia lies in their inability to monitor their own actions (Frith, 1992; Georgieff & Jeannerod, 1998), and to distinguish between imagination and reality (Bentall, Baker, & Havers, 1991; Brebion et al., 2000). Given the similarities between motor imagery and physical actions (Jeannerod, 1994; Jeannerod & Decety, 1995), one could suggest that this deficit of action monitoring is also found in schizophrenic patients when required to imagine performing a movement. Indeed, when one imagines oneself moving, one appeals to the same motor representations that one uses when one actually executes the movement. Motor imagery thus shares many properties with physical actions at the physiological level (muscle activity), at the kinematic level (similar physical constraints and laws) and at the neural level (shared patterns of brain activation, Grezes & Decety, 2001). Furthermore, patients with motor impairments such as parietal damage (Sirigu et al., 1995; Sirigu & Duhamel, 2001), Parkinson's disease (Dominey, Decety, Broussolle, Chazot, & Jeannerod, 1995; Lee, Harris, & Calvert, 1998) or lesion of the right basal ganglia (Harris, Harris, & Caine, 2002) also suffer from difficulties in motor imagery. Motor imagery provides thus a direct insight into action representations (Jeannerod, 1994) and is particularly relevant for the study of action in schizophrenia.

Several studies show a general impairment of action monitoring in schizophrenic patients (Daprati et al., 1997; Franck et al., 2001; Frith, 1992; Georgieff & Jeannerod, 1998). Patients appear to be unable to anticipate the sensory consequences of their own movements, that is, to produce a “forward model” of their actions (Wolpert, Ghahramani, & Jordan, 1995). The disruption of the forward model would lead to xenopathic experiences: patients can no longer compare the performed movement with the anticipated outcome of these movements and thus feel alienated from their own actions (Frith, Blakemore, & Wolpert, 2000). Positive symptoms such as hallucinations may thus be interpreted as a deficit of self-monitoring associated with a kind of overactivity of mental imagery: patients' inner life is particularly intense and vivid and the patients are unable to realize that their mental images come from themselves rather from the external world (Bentall & Slade, 1985; Horowitz, 1975).

The forward model involves the ability to mentally manipulate motor representations independently of action execution. Rather than inferring from the incorrect motor performance to the disruption of the forward model, we could directly evaluate the forward model by investigating motor imagery in schizophrenic patients. Two recent studies about schizophrenia investigated whether explicit imagined movements were constrained by the speed–accuracy trade-off given by Fitts' law. Patients were required to complete actual and imagined pointing task. In Danckert, Rossetti, d'Amato, Dalery, and Saoud (2002b), all schizophrenic patients showed poor relationship between imagined movement duration and target size. The authors concluded that they were unable to generate accurate internal images of their own actions independently of their symptom profile. However, their sample size was small. In contrast, in Maruff, Wilson, and Currie (2003), only the patients suffering from passivity symptoms were impaired in a similar task using different stimuli.

In our study, action representations were tested using mental rotation tasks involved in perceptual judgements. Both mirror recognition and handedness recognition automatically require motor imagery: subjects mentally rotate the stimulus to match the most common position (0°). As

shown by Cooper and Shepard (1975, 1984), durations of mental and physical rotation are both a function of the angular orientation of the stimulus. Mental rotation is endowed with the same temporal and kinematic properties as physical movements. More particularly, Parsons (1994) showed that simulated and real movements require the same time length for common and comfortable postures, and shorter but proportional time for less common or uncomfortable postures. Wexler, Kosslyn, and Berthoz (1998) also showed that when subjects carry out mental rotation of shapes and unseen motor rotation in a dual task paradigm, they are faster and more accurate when the direction of both rotations is similar, than when it is not. The change in the speed of the motor rotation influences even the speed of the mental rotation. Furthermore, mental rotation is partly based on the same cortical network as physical rotation. A number of brain imaging studies have identified activations in the primary motor and premotor cortex during mental rotation (Cohen et al., 1996; Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Tagaris et al., 1997; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999), while Ganis, Keenan, Kosslyn, and Pascual-Leone (2000) revealed that inhibition of the electrical activity of the primary motor cortex, using Transcranial Magnetic Stimulation (TMS), significantly slows down mental rotation. Nevertheless, several studies have shown that mental rotation involves two distinct neural systems, whether the stimulus is a body part rotated in the somatic space (Bonda, Petrides, Frey, & Evans, 1995; Gentilucci, Daprati, & Gangitano, 1998; Kosslyn et al., 1998; Parsons, 1994) or an object rotated in the visual space (Alivisatos & Petrides, 1997). Given the distortions of their body image, such as underestimation of extremities, desomatization, and boundary loss (Koide, Iizuka, Fujihara, & Morita, 2002; Priebe & Rohricht, 2001), in the present study, we wanted to determine whether schizophrenic patients would be more impaired in rotating the representation of their hand by comparison to letters.

In this study, we aimed to investigate action representations involved in motor imagery by addressing the following questions: (1) Are schizophrenic patients impaired in motor imagery both at the explicit and at the implicit level? (2) Are some stimuli more difficult for them to mentally rotate than others? (3) Is there any link between performance and symptom profile? The study of motor imagery is particularly relevant for investigating the degree of impairment of the forward model in schizophrenia. Based on the previous literature (Danckert et al., 2002b; Maruff et al., 2003), we expected that the patients would have difficulties in performing the tasks, both at the implicit and the explicit level. However, the results revealed to be more complex, emphasizing the necessity to draw sharp distinctions between different levels of action.

2. Materials and methods

2.1. Subjects

Thirteen right-handed (Oldfield, 1971) schizophrenic patients (12 males and 1 female; mean age 41.3 years \pm 12.1) were tested and gave informed consent for participation in the study. All patients were diagnosed as schizophrenics according to the DSM-IV. The mean average disease duration was 16.8 years \pm 11.4. All patients were receiving antipsychotic medication and were clinically stable at the time of testing. Vision was normal or corrected to normal. Six tests from the Birmingham Object Recognition Battery (BORB; Riddoch & Humphreys, 1993) assessed

Table 1
Demographic and clinical characteristics of schizophrenic patients (mean and *SD*)

	Hallucinated patients	Non-hallucinated patients	Schizophrenic patients (total)
Age	42 ± 15.9	40.5 ± 7.1	41.3 ± 12.2
Disease duration	15.9 ± 13.7	18 ± 9.3	16.8 ± 11.4
Education	9.4 ± 2.3	10.2 ± 2.6	9.8 ± 2.4
Laterality	84.3 ± 18.6	91 ± 13.9	87.4 ± 16.3
SAPS	28.9 ± 13.6	27.2 ± 17	28.1 ± 14.6
Hallucination sub-score	5.1 ± 2.5	0.3 ± 0.8	2.9 ± 3.1
SANS	44.9 ± 31.5	39.7 ± 24.6	42.5 ± 27.5
BORB2A	26.1 ± 1.5	27.2 ± 1.7	26.6 ± 1.6
BORB3A	26.6 ± 1.5	27.3 ± 1.2	26.9 ± 1.4
BORB4A	21.6 ± 5.4	23.5 ± 4.6	22.5 ± 5
BORB5A	31.1 ± 5.4	35 ± 1.8	32.9 ± 4.5
BORB7	22.9 ± 2.8	24.8 ± 0.4	23.8 ± 2.2
BORB11	32 ± 0	31.8 ± 0.4	31.9 ± 0.3
Haloperidol equivalents (mg)	13.2 ± 11.9	18.5 ± 5.7	15.6 ± 9.6

SANS, scale for the assessment of negative symptoms. SAPS, scale for the assessment of positive symptoms.

the patients' ability to process basic visual properties, such as length, size, orientation, and location, as well as the integrity of visual perception. To check the relation between motor imagery and some positive symptoms such as hallucinations, we classified the patients into two subgroups, a group of hallucinatory patients and a group of non-hallucinatory patients. According to clinical evaluation (Andreasen's scales for assessment of positive and negative symptoms, [Andreasen, 1983, 1984](#)), a clear pattern of hallucinations was present in seven patients (with a hallucination sub-score ≥ 3 , mean score = 5.1 ± 2.5). For the remaining six patients (with a hallucination sub-score < 3), the mean value was 0.3 ± 0.8 . The mean value for all the schizophrenic patients was 2.9 ± 3.1 . The hallucinations were mainly auditory-verbal (items 2 and 3 of the SAPS) (see [Table 1](#)).

Patients' performance was compared to that of 13 right-handed control subjects (10 males and 3 females; mean age 29.4 years ± 8.4), who volunteered for the study. The mean educational level of the control group was 13.9 years ± 4.3 . None had a history of neurological or psychiatric illness. There was no significant difference between the schizophrenic and the control group for age, sex and handedness, although the control subjects received significantly more education.

2.2. Apparatus and procedure

The stimuli were presented on a Macintosh Powerbook G3 computer. Their size was approximately 7 cm on the computer screen and they were drawn in grey levels on a white background. The subjects were seated 50 cm from the screen. Response time and errors were recorded by the computer.

There were three conditions, with three types of stimuli: hands, gloves, and letters/numbers.

2.2.1. Hands

The hand stimuli were adapted from those developed by [Parsons \(1994\)](#). They consisted of drawings of a left and a right hand viewed from four perspectives, two in 2D (palm, back) and

two in 3D (fist, grasp). Subjects had to decide whether the stimulus displayed on the screen was a right or a left hand. They were asked to respond as fast and accurately as possible, by pressing a key labelled “left” or “right” on the computer keyboard with the left and right index, respectively.

2.2.2. *Gloves*

The glove stimuli were obtained by subtly altering the hand stimuli. The instruction was to imagine that one puts one’s own hand in the glove and to decide whether it was a right or a left hand. As in the Hand Condition, subjects were asked to respond as fast and accurately as possible by pressing a key labelled “left” or “right” on the computer keyboard with the left and right index, respectively.

2.2.3. *Letters/numbers*

The stimuli consisted of capital letters (F or R) and Arabic digits (5 or 7) written in Times New Roman. They were presented either in mirror or in normal orientation. Subjects were instructed to determine whether the stimulus that appeared on the screen was written in a normal way or in mirror. They were asked to respond as fast and accurately as possible by pressing a key labelled “mirror” or “normal” on the computer keyboard with the left and right index finger, respectively.

For each condition, the drawing was presented in eight different angular orientations, ranging from 0° to 315° clockwise, from the normal upright, in 45° steps, which resulted in a total number of 64 stimuli. Each of the 64 stimuli repeated three times for a total of 192 trials. The 192 trials were organized in six blocks of 32 trials, with an equal number of stimuli of each type and orientation. Blocks were constructed with the constraint that a left or a right hand/gloves (and a mirror or a normal letter/number) never appeared more than twice in a row and that the same orientation never appeared twice in a row.

Four practice trials were given at the beginning with stimulus orientations that have never been used. In the training session feedback was given. The subject was then given the possibility of verifying her/his production and querying for further information. The examiner accurately verified that the subjects would understand and maintain the instructions in the course of the experiment by recalling them the instructions and by asking them to repeat them. Each trial began with a fixation point that lasted for 1000 ms. Then the screen turned white for 100 ms, and the stimulus appeared and remained on the screen until the subject’s response. Then the screen turned white again for approximately 1000 ms and the fixation point appeared again to announce the next trial. No feedback was given to the subjects. Subjects were instructed to make no movement when processing the stimuli. All the subjects carried out the three conditions in a random order, at three different times.

2.3. *Data analysis*

For the three conditions, we analysed mean response times of correct responses (RT in ms) and the error rate (ER). To be able to distinguish between the imagined rotation process and the perceptual processes that also contribute to task performance, we computed the slopes and intercepts of the ER and RT rotation functions (from 0° to 180°). These analyses included a repeated-measures ANOVA, with the factors of group, condition, laterality, and orientation. Concerning the condition factor, we made two kinds of analysis: (1) by comparing the three conditions (Hand,

Letter and Glove); (2) by comparing the mean of the conditions Glove and Hand (combined Body condition) and the condition Letter. Finally, we compared results of hallucinatory patients with those of non-hallucinatory patients.

The Bonferroni/Dunn test was used for post hoc comparisons. The significant threshold for all analyses was set at $p < .05$ for the ANOVA test and $p < .0018$ for the Bonferroni/Dunn test.

3. Results

3.1. Response times

A repeated-measures ANOVA on the three conditions for the mean RT showed a significant main effect of group ($F(1, 23) = 8.11$; $p = .0091$), schizophrenic patients (mean = 2689 ± 1381) being slower than the control group (mean = 1516 ± 603). A significant main effect of the orientation was also found ($F(7, 161) = 15.34$; $p < .0001$) (see Fig. 1). No significant interaction of orientation by group was observed. A bilateral no-paired t test showed that the slope of the RT rotation function was the same for the two groups ($p = .9259$). In contrast, the intercept was significantly different, controls requiring half as much time as the patients (controls mean = 1270 ± 420 ; schizophrenics mean = 2537 ± 1164 ; $p = .0011$).

There was no apparent effect of condition. However, the interaction of orientation by condition was significant in the comparison between the combined condition Body and the condition Letter, ($F(7, 161) = 2.71$; $p = .011$). Therefore, we made post hoc analysis on the condition factor. The Bonferroni/Dunn test analysis showed a significant difference between the conditions Body and Letter ($p = .0025$), the response being faster for the Letter than for the Body (see Fig. 2). No significant interaction of group by condition was observed.

We also excluded the condition Letter and performed specific analyses of variance ANOVA only on the combined condition Body that showed the same effects as the previous analyses on the three conditions (group and orientation). Moreover, a significant main effect of the laterality was found, $F(1, 19) = 10.33$; $p = .0046$, the response being slower for the left hand/glove

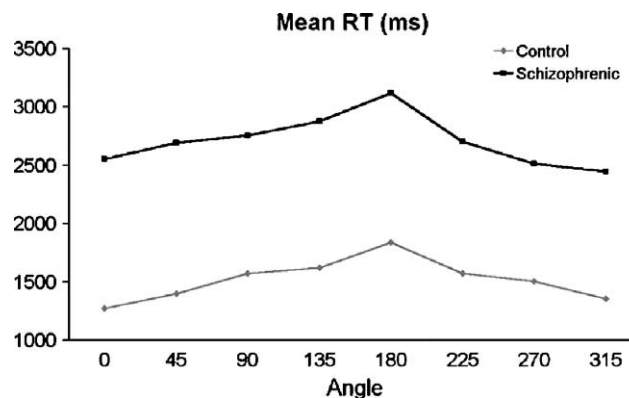


Fig. 1. Mean reaction time in controls and schizophrenic patients, all conditions confounded.

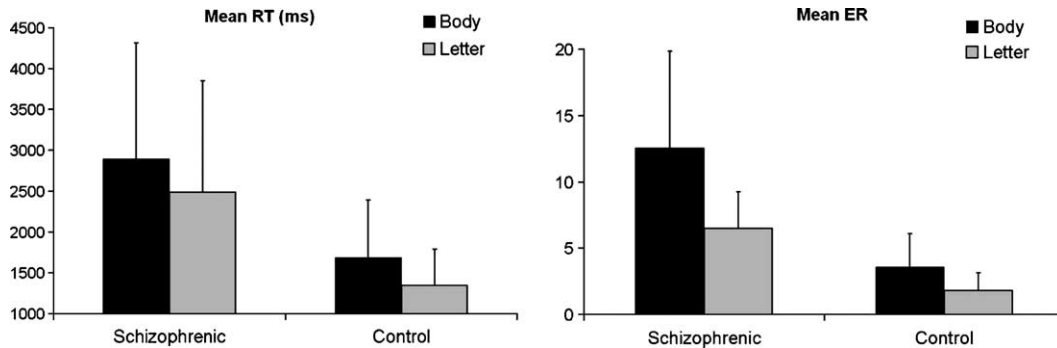


Fig. 2. Mean reaction time and mean error number in controls and schizophrenic patients for the Body (Hand + Glove conditions) and the Letter conditions.

(mean = 2350 ± 1485) than the right hand/glove (mean = 2212 ± 1381). This effect interacted with the orientation factor ($F(7, 133) = 2.32$; $p = .029$). We also found a significant interaction of the laterality by the orientation and the group ($F(7, 133) = 2.32$; $p = .018$). This effect is mainly due to a peak at 180° for the left hand in schizophrenics. However, no significant interaction of laterality by group was observed.

3.2. Accuracy

A repeated-measures ANOVA on the three conditions for the mean ER showed a significant main effect of group ($F(1, 24) = 24.81$; $p < .0001$), schizophrenic patients making more errors than controls. A significant main effect of the orientation was also found ($F(7, 168) = 18.01$; $p < .0001$). The analysis also showed a significant interaction of orientation by condition ($F(14, 336) = 5.56$; $p < .0001$), which is mainly due to the huge increase of errors at 180° in the Letter Condition (for instance, $0^\circ, 180^\circ$: $p < .0001$; $45^\circ, 180^\circ$: $p < .0001$; $90^\circ, 180^\circ$: $p < .0001$). No significant interaction of orientation by group was observed.

There was no significant difference between the three conditions (Hand, Glove, Letter). However, the repeated-measures ANOVA made on the comparison between the combined condition Body (Hand + Glove) and the condition Letter showed a significant main effect of condition ($F(1, 24) = 19.57$; $p = .0002$), the subjects making more errors for the Body than for the Letter (see Fig. 2). A significant interaction of condition by group was observed ($F(1, 24) = 5.82$; $p = .024$). See Fig. 3.

We performed specific analyses of variance ANOVA on only the combined condition Body, which showed the same effects as the previous analyses on the three conditions (group and orientation). Moreover, a significant main effect of the laterality was found ($F(1, 24) = 5.33$; $p = .03$), both groups making more errors for the left hand/glove than the right hand/glove. No significant interaction of laterality by group was observed.

3.3. Symptom profile and schizophrenic subjects' performance

The analysis of the mean RT on the three conditions showed no significant effect of the subgroup (hallucinatory versus non-hallucinatory). There was no significant difference in the slope

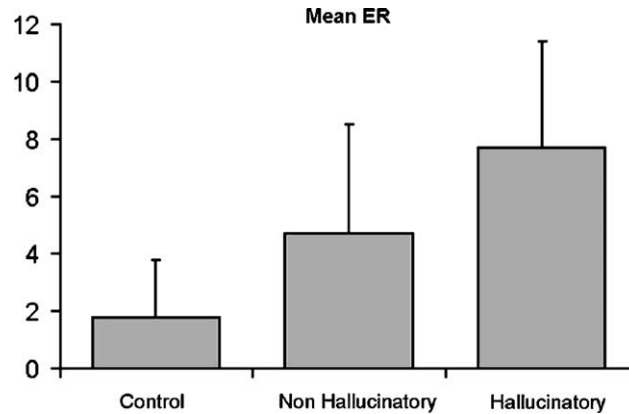


Fig. 3. Mean error number in controls, non-hallucinatory patients, and hallucinatory patients, for the three conditions (all degrees confounded).

and in the intercept of the RT orientation function between hallucinatory and non-hallucinatory subjects. However, the Bonferroni/Dunn test analysis of the ER revealed a significant effect of the presence of hallucinations, the hallucinatory patients making more errors in comparison to the non-hallucinatory ones ($F(2, 23) = 18.58$; $p < .0001$) (all degrees confounded) (see Fig. 3).

The ER was not correlated with SANS and SAPS score. No correlation between performance and dose of anti-psychotic agents was found.

4. Discussion

The present study aimed to evaluate schizophrenic patients' abilities in performing a motor imagery task. The main results can be articulated into two parts. On the one hand, the schizophrenic patients displayed the same pattern of performance as the control subjects (same effects of orientation, condition and laterality). On the other hand, they were significantly slower and less accurate. Interestingly, patients suffering from hallucinations made significantly more errors than non-hallucinatory patients.

As a preliminary step, we investigated the nature of the process involved in handedness judgements. We designed the Glove condition, which explicitly requires imagining moving one's own hand, to assess that the same mechanism was involved in the Hand condition, which relies only implicitly on mental imagery. We found no significant difference in terms of reaction time or accuracy when we compared the two conditions, both for controls and for schizophrenic patients. This lack of difference argues in favour of the hypothesis that the Hand condition depends on motor imagery. Furthermore, on debriefing, all the subjects reported using mental rotation for the perceptual judgement in all the conditions.

We found that the overall pattern of performance of schizophrenic patients was similar to the controls. Our results showed that the ability to mentally rotate stimuli was preserved in schizophrenia, both at the implicit and the explicit level. In both groups, the reaction time was a function of the angular orientation of the stimulus. The slope of the rotation function was almost the

same, indicating that patients and controls could produce mental rotation at the same rate. We did not compare mental rotation with physical rotation, but we can suggest based on our results that mental rotation in schizophrenia followed the same temporal and kinematic law as physical movements. This result can be contrasted with the performance of patients suffering from action deficit, who do not display the expected mental rotation function (Dominey et al., 1995; Harris et al., 2002; Lee et al., 1998; Sirigu et al., 1995; Sirigu & Duhamel, 2001). Indeed, several studies showed that motor processes play a role in body-based mental rotation as well as object-based mental rotation (Ganis et al., 2000; Wexler et al., 1998). Motor imagery is part of the broader phenomenon of motor representations involved in the preparation of action (Jeannerod, 1994). We may therefore suggest that the representation of action that is involved in mental rotation is at least partially preserved in schizophrenia. These results are not so surprising given that only one third of schizophrenic patients suffer from neurological soft signs like disruption of motor coordination and they do not suffer from any kind of apraxia (Flashman, Flaum, Gupta, & Andreasen, 1996). Furthermore, some studies revealed that schizophrenic patients are able to correctly monitor their own movements (Fournieret, Franck, Slachevsky, & Jeannerod, 2001). Hence, schizophrenia should not be interpreted as an overall motor deficit, but more cautiously as a disruption of some action representations involved in specific contexts. Our results do not challenge the possibility that other aspects of motor imagery that emphasize a greater degree of accuracy could be impaired in schizophrenia, as shown by Danckert et al. (2002b) and Maruff et al. (2003).

Similarly, we found no difference between schizophrenic patients and controls concerning the comparison between the Body and the Letter conditions. Consistent with the literature, all subjects took more time and made more errors in the Letter condition than in the Body condition. These two conditions involve different brain areas and different mechanisms (Kosslyn et al., 1998). To identify handedness, subjects mentally rotate their dominant hand to match the stimulus, rather than the visually presented picture of the hand/glove (Gentilucci et al., 1998; Nico, Daprati, Rigal, Parsons, & Sirigu, 2004; Sirigu & Duhamel, 2001; Thayer, Johnson, Corballis, & Hamm, 2001). Thus, mental rotation of body parts involves the body schema and motor processes. On the contrary, mental rotation of objects takes longer (Kosslyn et al., 1998) and involves more general cognitive processes, and in particular visual imagery. We expected that schizophrenic patients would encounter more difficulties in the Body conditions as they suffered from body distortions (McGilchrist & Cutting, 1995; Priebe & Rohricht, 2001). Contrary to our expectations, schizophrenic patients did not show any specific impairment in the hand/glove condition, in comparison with the Letter condition. They displayed a laterality effect, also found in normal subjects (Gentilucci et al., 1998; Parsons, 1987). These findings suggest that the sensori-motor representation of the hand/arm is preserved in schizophrenia. This is not inconsistent with the literature if we distinguish the body schema used for action and the body image used for identification of the body size and shape (Gallagher, 1995). Dymorphophobia affects the latter while mental rotation of the hand involves the former, which seems to be preserved in our schizophrenic group.

The first part of our results revealed the same pattern of performance, which is typical of mental rotation, in schizophrenic patients and controls. Nevertheless, we could not conclude that there was no impairment in motor imagery as the patients were slower and less accurate. First, all the patients were significantly slower than the controls. Similarly, Starker and Jolin (1982) and David and Cutting (1993) reported that schizophrenic patients displayed a greater reaction time in auditory and visual imagery in comparison with controls, which might indicate that imagery

tasks were more difficult for them to accomplish. It could also express the generalized slowing down of schizophrenic mental process (Nelson et al., 1990). There is a massive difference in the intercept of the rotation function between the two groups, suggesting that patients are impaired not at the level of mental rotation per se, but rather at the level of the processes required by the perceptual judgments (perceptual registration and recognition of the shape). Consequently, we may suggest that the difference in accuracy across patients and controls is due to a general impairment of attention and working memory in schizophrenia, which can affect these perceptual processes (Goldman-Rakic, 1994; Park & Holzman, 1992; Salame, Danion, Peretti, & Cuervo, 1998). Indeed, motor imagery involves the activation of working memory and more specifically, the visuo-spatial sketchpad, which is specialized in the storage of mental images, following the off-line simulation of the movement (Annett, 1995; Baddeley, 1992; Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001). Recent studies have documented abnormalities in schizophrenia in spatial delayed-response tasks (Chen, Nakayama, Levy, Matthysse, & Holzman, 1999; Fleming et al., 1997; O'Donnell et al., 1996; Park & Holzman, 1992). A dysfunction of working memory would lead to the breakdown of behaviours guided by internal representations such as mental rotation. However, this hypothesis cannot fully account for our results. More particularly, a visuo-spatial impairment cannot explain why hallucinatory patients made significantly more errors than non-hallucinatory patients. Pantelis, Stuart, Nelson, Robbins, and Barnes (2001) showed that patients with negative symptoms displayed significantly greater deficits in performance on spatial working memory tasks, but we checked that the SANS score was not significantly different between the two subgroups, nor was it correlated to the accuracy. As far as we know, no study has found any correlation between hallucination and spatial working memory deficit in schizophrenia. Unfortunately, we did not assess the visuo-spatial sketch pad in our patients and further experiments would be necessary to evaluate the disruption of the spatial working memory and its relation to mental rotation.

We would rather here provide some possible explanation of the hallucinatory patients' performance by pointing toward the relationship between hallucination and the disruption of motor imagery. Most of the studies have focused on the vividness of imagery in schizophrenia and have displayed contradictory results (Aleman, de Haan, Bocker, Hijman, & Kahn, 2002; Heilbrun, Blum, & Haas, 1983; Horowitz, 1975; Mintz & Alpert, 1972; Seal, Aleman, & McGuire, 2004). By contrast to these studies, we preferred to use an objective measure in order to evaluate mental imagery and we solely investigated motor imagery, rather than perceptual imagery. We found that hallucinatory patients were not slower than non-hallucinatory patients, but were still less accurate. They displayed difficulties in monitoring the mental image of the rotation movement. Consequently, perturbation of mental rotation can be interpreted as a disruption of action monitoring in schizophrenia. Indeed, mental rotation engages the same brain areas as real movements, and more particularly the parieto-frontal system, which plays a key role in motor control (Alivisatos & Petrides, 1997). Our results fit the general picture of schizophrenic positive symptoms as disruptions of action monitoring (Frith, 1992; Frith et al., 2000). Following Frith and Done (1989); Malenka, Angel, Hampton, and Berger (1982) revealed that schizophrenic suffering from delusions of control showed difficulties in correcting errors produced during the execution of a movement directed toward a target in displacement without any visual feedback. Similarly, Turken, Vuilleumier, Mathalon, Swick, and Ford (2003) found that schizophrenic patients were unable to correct errors without external feedback, while they had no attentional deficit. The disruption

of self-monitoring may lead to the confusion between self-generated and externally generated movements, such as displayed in positive symptoms in schizophrenia. In an ‘alien hand’ task, [Franck et al. \(2001\)](#) showed that patients with passivity symptoms suffered from difficulties in correctly attributing the movement that they saw and replied randomly when they were given a weakly biased visual feedback (until 300 ms of delay and 30° of angular deviation). Similarly, verbal hallucinations can be interpreted as resulting from the misattribution of the inner speech ([Frith & Done, 1989](#); [Frith & Dolan, 1998](#); [McGuire et al., 1996](#); [Silbersweig et al., 1995](#)).

This impairment of action monitoring could result from the disruption of the forward model, which anticipates the sensory feedback that is compared with the prior intention and the actual feedback ([Frith et al., 2000](#)). Disturbances in mental rotation in hallucinatory patients point toward a similar disruption of the forward model. Motor imagery requires subjects to generate an internal image of an intended action and to anticipate the consequences of that action as if it had actually been carried out ([Jeannerod, 1994](#)). The present results suggest that hallucinatory patients were not able to update spatial representations as a consequence of their rotations. Indeed, patients did not have any visual feedback about the accuracy of their rotating movement as the physical rotation was not actually performed. Consequently, they were unable to precisely control the imagined movement. The final state of the rotation did not match the visual display of the stimulus. Furthermore, we may speculate that in the absence of visual feedback on their movement, hallucinatory patients would have more difficulties in accessing to the final state of the mental rotation ([Frith et al., 2000](#)). What they are aware of at the end of the process of mental rotation is different from what they see. This discrepancy leads to errors in the perceptual judgment. In the lack of a perfect matching, they would have to provide an approximate response. Following [Maruff et al. \(2003\)](#), we would like to interpret the correlation between hallucinations and lack of accuracy in mental rotation as the result of a similar deficit of action monitoring and action awareness.

Schizophrenic patients are not only impaired at the level of physical movements, but also at the level of imagined movements. This impairment is likely to reflect dysfunction in parietal association cortices that have been shown to be crucial for making use of forward models of goal-directed movements, as well as for updating spatial representations as a consequence of those actions. This parietal cortical association area is involved in perception of space and has been found to be active during execution, observation and imagination of movements, as well as for action attribution ([Farrer & Frith, 2002](#); [Parsons, 2003](#)). Schizophrenic patients with passivity showed hyperactivation of parietal and cingulate cortexes ([Franck, O’Leary, Flaum, Hichwa, & Andreasen, 2002](#); [Spence et al., 1997](#)). Interestingly, most of the fMRI studies found parietal activation during mental rotation of every kind of stimuli ([Alivisatos & Petrides, 1997](#); [Kosslyn et al., 1998](#); [Vingerhoets, de Lange, Vandemaele, Deblaere, & Achten, 2002](#)). Taken together these results may suggest an impairment of the parietal cortex, which is crucial for generating and making use of forward models of intended actions and which would be implied both in the disruption of mental rotation and in the presence of hallucinations ([Danckert et al., 2002b](#), [Danckert, Saoud, & Maruff, 2004](#)).

In summary, we demonstrated that schizophrenic patients were still able to mentally rotate hands as well as letters, given the correlation between their reaction time and the orientation of the stimuli. We concluded that motor imagery was partially preserved and that their performance, which was slower and less accurate, could be explained by generalized cognitive deficits such as the impairment of the spatial working memory. However, this latter deficit cannot explain the in-

creased amount of errors in patients suffering from hallucinations. Consequently and consistent with the literature, we suggested that action monitoring processes might be disturbed, possibly following an impairment of the parietal cortex.

We may interpret these results as expressing the dissociation between two levels of action representation in schizophrenia. The characteristic rotation pattern of performance in schizophrenic patients revealed that the patients actually intended the imagined movement and mentally represented the rotation, while the difficulties displayed by the hallucinatory patients showed that the lack of visual feedback prevented them from precisely monitoring their movements and becoming aware of them. We thus distinguish two levels in motor representations: (i) the rough-grained representation of the intended movement; (ii) the fine-grained representation of the performed movement resulting from the forward model, which is normally compared to the sensory feedback (Blakemore, Wolpert, & Frith, 2002). Our results seem to indicate that the representation of the intended movement was preserved in all the schizophrenic patients, while the forward model would be impaired in those of the patients who suffered from hallucinations. In this sense, our results are consistent with the literature (Danckert et al., 2002a, 2002b, 2004; Maruff et al., 2003). Indeed, the discrepancy between the distance of the movement and the width of the target in pointing tasks revealed the lack of accuracy of the forward model in schizophrenia, while the correlation between the duration of the movement and the orientation of the stimulus in mental rotation tasks demonstrates that the global trajectory of the intended movement is intact. It is thus likely that these tasks evaluate different kinds of action representation.

The present study provides novel evidence about the dissociation between the representation of the intended movement and the representation of the anticipated movement: the former turn out to be intact in schizophrenic patients, while the latter is disturbed in hallucinatory patients. However, it only provides preliminary results, which should be replicated with a larger sample of patients. Because our group was small, the current report did not permit strong generalization. Furthermore, it would be interesting to compare patients suffering from hallucinations and patients suffering from delusions of influence, so that we could more directly relate our results with Maruff's ones. Based on previous studies, we do not expect any massive difference (Daprati, Nico, Saimpont, Franck, & Sirigu, 2005; Franck et al., 2002).

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