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Impaired Passive Maintenance and Spared Manipulation of Internal Representations in Patients With Schizophrenia

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Working memory (WM) impairment is a core feature of schizophrenia (SZ), but the integrity of the various components of WM is unclear. After encoding, mental representations must be maintained in WM during the delay period. In addition to maintenance, manipulation of internal representation can occur in WM. It has been argued that manipulation of items in WM is more impaired than simple maintenance in SZ, but direct empirical data to support this claim have been mixed. Discrepant findings among studies might be explained by task parameters, specifically the degree to which the manipulation task places demands on encoding and maintenance processes. The present study set out to examine these components of WM in patients with SZ ($n = 20$) and demographically matched healthy controls ($n = 19$) using a spatial delayed response task (DRT) to measure maintenance processes and 2 mental rotation tasks (allocentric and egocentric) with no delay period or restriction on encoding time to measure manipulation processes. Consistent with previous findings, patients were impaired on the spatial DRT. However, patients performed equally well on the egocentric mental rotation task and were more accurate than controls on the allocentric mental rotation task as the required degree of rotation increased. These results indicated impaired maintenance and spared manipulation of representations in WM and suggest a pocket of cognitive function that might be enhanced in SZ.

Key words: Working memory/mental rotation/self-other transformation/schizophrenia/maintenance/manipulation

Introduction

Patients with schizophrenia (SZ) demonstrate deficits in working memory (WM) across a wide range of experimental tasks.[1] Furthermore, these deficits are present in unaffected relatives[2,3] and in the prodromal phase of illness,[4] and they persist even when symptoms have remitted.[5] Baddeley's model[6] posits that WM comprises modality-specific subsystems that support the central executive, which allocates resources. One of the modality-specific subsystems is the "visuospatial sketchpad," which utilizes imagery to support internal representation in WM. The ability to hold internal representation online passively and to manipulate the internal representation both contribute to successful WM, but the extent to which maintenance and manipulation components of WM are affected in SZ remains to be fully elucidated. The goal of the current study was to examine the integrity of maintenance and manipulation components of WM in SZ, using 2 mental rotation paradigms and a spatial delayed response task (DRT).

It is generally assumed that manipulation processes are more severely affected in SZ. This supposition is based largely on findings of impaired executive functioning,[7] which refers to those cognitive abilities that are involved in the control of thought and behavior, and poor performance on the *n*-back task,[8] which is argued to tax WM manipulation processes. Although convincing direct experimental evidence to support this claim has been limited, a handful of recent studies have attempted to dissociate maintenance and manipulation processes in SZ. Kim and colleagues[9] used a variant on a spatial DRT that included both a condition in which subjects had to maintain the information during a delay (maintenance only) and a condition in which subjects had to manipulate the spatial array by mentally flipping the display horizontally and maintain the flipped array during the delay period (maintenance and manipulation). In a verbal equivalent of this task, participants were instructed to remember consonant-vowel syllables over a delay period (maintenance only) or alphabetize and maintain those syllables over the delay period (maintenance and manipulation). They found that in both verbal and spatial domains, accuracy in SZ was disproportionately affected

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by the added manipulation demand, and the authors argued that the manipulation component of WM is more severely impaired than maintenance.

However, other groups have failed to replicate this finding. Schlösser et al[10] used a similar letter reordering paradigm and found that although patients performed worse overall, their accuracy was not disproportionately affected by the added manipulation demand. Similarly, Hill and colleagues[11] found that added manipulation demands did not differentially affect patients' performance on a verbal WM task, even at increasing WM loads. In fact, they found that the magnitude of WM deficit in the SZ compared with control group was smaller with the added manipulation demand. In a recent study, Quee and colleagues[12] also found that after a 500 ms delay following target onset in a match-to-sample task, SZ patients were not disproportionately impaired compared with controls when required to mentally rotate the stimulus. Given mixed findings in this area, it is impossible to draw firm conclusions about deficits in WM maintenance vs manipulation in SZ. Furthermore, none of, these studies include a manipulation condition in which maintenance and encoding demands were minimal, with no delay period and no limited encoding period. Thus, it is unknown whether manipulation itself is intact or not.

Mental rotation paradigms, which require mentally rotating a stimulus into a particular orientation relative to its own reference frame (allocentric mental rotation) or mentally rotating oneself into a particular orientation relative to the surrounding environment (egocentric mental rotation), allow for the parametric investigation of manipulation of internal representations. WM is crucial for mental rotation,[13,14] and it has been argued that mental rotation is a better index of the ability to actively manipulate contents of WM than the *n*-back task, for instance.[14] Because reaction times (RTs) for mental rotation correspond to RTs for physical rotation, with speed and accuracy decreasing as the required angle of mental rotation increases,[15] the extent of spatial manipulation of the internal representation of the stimulus can be quantified.

Few studies have examined mental rotation ability in SZ. De Vignemont and colleagues[16] found that although SZ patients were slower and less accurate than controls overall on in-plane mental rotation tasks, they showed the same decrement in performance and speed with increasing angles of rotation as healthy controls (HCs). That is, they were not more impaired than controls by the increasing manipulation demands. Two studies have investigated patient performance on a 3-D mental rotation task. In the experimental condition of this task, subjects are presented with 2 shapes that are either identical or mirror images of each other and 1 shape is rotated along its vertical axis relative to the other shape. In the control condition, the 2 shapes are presented at the same angle of rotation. Subjects are required to indicate whether the 2 shapes are identical or mirror images of each other. Halari and colleagues[17] found that although patients were slower and less accurate overall, they were no more impaired in the experimental condition than in the control condition that did not require mental rotation. Similarly, Jiménez and colleagues[18] do not report differential performance in the experimental vs control task relative to healthy participants. Thus, the existing data do not unequivocally support impaired WM manipulation in SZ.

To summarize, although a somewhat accepted notion, there is very little empirical evidence to support the claim that manipulation of mental representations in WM is more impaired than maintenance in patients with SZ. In studies that have attempted to directly compare these 2 components of WM in SZ, a crucial piece of evidence has not been presented; manipulation has not been tested without an accompanying maintenance demand. Such data would provide an important piece of the puzzle for unraveling the different contributions of components of WM on the observed deficits in SZ.

The goal of the current study was to investigate mental rotation in SZ to elucidate manipulation of representations of objects and self in WM. Because there is evidence that egocentric and allocentric mental rotation can be dissociated at the level of both behavior and brain,[19] we investigated performance using both internal and external reference frames. Allocentric mental rotation was measured with an in-plane letter rotation task, and egocentric mental rotation was measured using an imagined self-other transformation task, in which subjects were instructed to imagine themselves in the perspective of a figure on the screen in order to make a side decision. Additionally, we administered a spatial DRT to measure passive maintenance in WM. We hypothesized that patients would show a deficit in maintenance and perform worse on the spatial DRT, consistent with previous findings.[20] However, we also hypothesized that when maintenance and encoding demands were minimized by the absence of a delay period and no limit on the encoding period, the ability to manipulate items in WM would be intact in patients, as indexed by equal RT and accuracy costs of greater mental rotation in patients and controls. That is, WM manipulation, but not maintenance, would be spared in patients with SZ.

Methods

Participants

Twenty SZ outpatients were recruited from an outpatient psychiatric facility in Nashville, TN. Diagnoses were made according to the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria using structured clinical interviews (SCID-IV).[21] Seventeen patients were taking an atypical

Table 1. Demographic Characteristics of the Patient and Control Groups

	Patients Mean(SD)	Controls Mean (SD)	*t*	*P*
Age	38.4 (9.2)	39.5 (8.9)	0.37	.71
Sex	7 females/ 13 males	11 females/ 8 males	Phi = 2.06	.20
Edinburgh handedness	56.3 (44.8)	76.8 (46.4)	1.41	.17
Years of education	14.1 (2.3)	15.4 (2.1)	1.86	.07
IQ	104.1 (9.7)	106.9 (7.9)	1.00	.32
SWM accuracy (%)	87.7% (10.9%)	94.8% (7.6%)	2.29	.03
SAPS	21.0 (17.4)			
SANS	24.4 (17.3)			
BPRS	14.3 (8.1)			

Note: SAPS, Scale for the Assessment of Positive Symptoms; SANS, Scale for the Assessment of Negative Symptoms; BPRS, Brief Psychiatric Rating Scale.

antipsychotic medication (risperidone, olanzapine, clozapine, paliperidone, quetiapine, and ziprasidone), 1 patient was taking a typical antipsychotic medication (thiothixene), 1 patient was taking valproic acid, and 1 patient was taking lamotrigine. Clinical symptoms were assessed with the Brief Psychiatric Rating Scale,[22] the Scale for the Assessment of Positive Symptoms,[23] and the Scale for the Assessment of Negative Symptoms.[24] Nineteen HC participants without a history of DSM-IV Axis I disorder were recruited from the same community by advertisements. All subjects were screened for neurological disorders and past head injury.

Intelligence was assessed with the Adult North American Reading Test (ANART),[25] which measures premorbid intellectual functioning. ANART scores were not available for 2 patients and 3 controls; for these participants, the Wechsler Abbreviated Scale of Intelligence[26] was used. Handedness was assessed using the Modified Edinburgh Handedness Inventory.[27] Edinburgh scores range from −100 (completely left-handed) to +100 (completely right-handed). All subjects had normal or corrected-to-normal vision. All participants gave written informed consent approved by the Vanderbilt Institutional Review Board and were paid. The 2 groups were matched for age, sex, IQ, years of education, and handedness. Demographic characteristics are outlined in table 1.

Tasks

People Rotation Task. We used stimuli similar to those used in previous studies of perspective-taking and mental self-other transformations.[28] A photograph of an individual with 1 arm raised either out to the side or across his body faced either toward or away from the participant and was subtended by −35° to 35° from the upright position, in 10° steps (figure 1A). Different angles of presentation is common practice in studies of imagined self-other transformations[28,29] and were used in order to discourage participants from memorizing associations between particular stimuli and motor responses.[30] Stimulus presentation and response collection were controlled by Matlab. Stimuli extended 12° of visual angle horizontally and vertically and were presented in the center of the computer screen until a response was made or after a 10 s time-out period. Subjects were instructed to respond as quickly and accurately as possible. A black fixation cross was presented during the 1000-ms intertrial interval before the next trial could begin. Trials in which the subject did not respond within the 10 second time-out period were excluded from further analysis.

Each participant completed blocks of trials under 2 different sets of instructions. The order of instruction was counterbalanced across subjects. Each set of instructions consisted of 128 total trials, divided into 2 blocks, which consisted of 32 repetitions of each condition of interest (perspective and arm position) in a randomized order. For each set of instructions, participants would perform 1 block with each hand. Order of response hand was counterbalanced across subjects.

Perspective-taking Instruction. Participants were asked to imagine themselves in the position of the figure on the screen and indicate whether the raised arm would be their right or left arm by pressing a key labeled "L" and "R." A left judgment was indicated by the left key press, and a right judgment was indicated by the right key press, using their middle and index fingers.

Side Judgment Instruction Participants were asked to decide whether the raised arm was pointing toward the left or right side of the screen and indicate their response by pressing a key labeled "L" and "R." A left judgment was indicated by the left key press, and a right judgment was indicated by the right key press, using their middle and index fingers. Under this set of instructions, no imagined transformation was required.

Letter Rotation Task. A number or letter (F or 5) was presented in either mirror or normal orientation at 1 of 8 different angular orientations, ranging from 0° to 315° clockwise, from the upright position, in 45° steps (figure 1B). Participants were asked to indicate whether the letter was presented in normal or mirror orientation by pressing a key labeled "N" or "M" with their index and middle finger. Stimulus presentation and response collection were controlled by Matlab.

Stimuli extended 6° of visual angle horizontally and vertically and were presented in the center of the computer screen until a response was made or after a 10

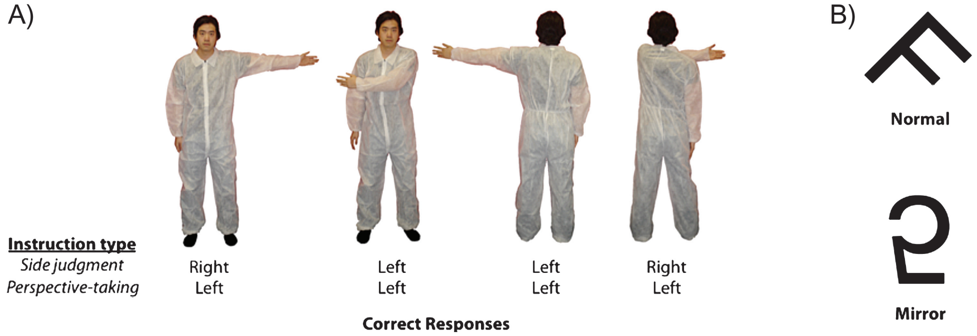

Fig. 1. Experimental Stimuli in the (A) People Rotation Task and (B) Letter Rotation Task.

seconds time-out period. A black fixation cross was presented during the 1000-ms intertrial interval before the next trial could begin. The experiment consisted of 512 total trials, divided into 8 blocks, which consisted of 16 repetitions of each stimulus type in a randomized order. Participants performed 4 blocks with each hand. Order of response hand was counterbalanced across subjects. Trials in which the subject did not respond within the 10 second time-out period were excluded from further analysis.

Spatial DRT. Spatial WM was assessed using a DRT with an intervening task that does not interfere with the spatial memory.[3] The trial began with a fixation cross in the center of the screen. Then the target, a black circle subtending 2°, was presented pseudorandomly at 1 of 8 locations, 12° from central fixation and separated by 45°, for 300 ms. Participants were required to maintain this target in WM for 8 seconds. During the delay, 3-digit numbers were presented, one per second, in descending order by 4. Subjects were instructed to note any subtraction errors, when the difference between 2 consecutive numbers did not equal 4. The purpose of the intervening task was to prevent verbal rehearsal of the spatial location of the target during the delay and to ensure that subjects were fixating centrally rather than at the target location. Past studies using the spatial DRT [3,20,31] have shown that the number subtraction intervening task does not interfere with the spatial representation in WM in either SZ patients or controls. After the 8 second delay, the central fixation cross reappeared, and subjects were instructed to indicate the remembered location of the target. After the subject responded, a screen was presented asking the participant to indicate if they noticed a subtraction error using a key press corresponding to yes and no. There were 48 trials. spatial DRT scores were not available for 1 patient and 1 control subject.

Testing Procedure

A chinrest was used to stabilize head position for the mental rotation tasks. Task order was counterbalanced across subjects. Subjects practiced the mental rotation tasks until 5 consecutive responses were correct. Subjects also received 5 practice trials of the DRT.

Data Analysis

Separate repeated measures ANOVAs were conducted on mean RT and error rate in the people and letter rotation tasks, with diagnostic group entered as a between-subject variable. For the people rotation task, instruction (perspective taking or side judgment), perspective (front or back), and arm position (crossed or not crossed) were entered as within-subject variables. For the letter rotation task, letter orientation (normal or mirror) and angle of rotation were entered as within-subject variables. Independent *t*-tests were conducted to compare performance on the spatial DRT. All tests were 2-tailed.

Results

People Rotation Task

The number of trials excluded from analyses due to the subject not responding within the 10 seconds time window was low (HC: 0.26 ± 0.65; SZ: 0.40 ± 0.75) and did not differ between groups ($t_{37} = 0.60$, $P = .55$).

Errors. Results are displayed in figure 2A. There was a significant effect of instruction ($F_{1,37} = 19.1$, $P < .001$), with error rates being higher under the perspective-taking instruction than the side judgment instruction. There were also significant main effects of perspective ($F_{1,37} = 6.0$, $P = .02$) and arm position ($F_{1,37} = 4.8$, $P = .04$), with higher error rates when the stimulus was facing front vs back and when arms were crossed vs not crossed. Importantly, there was also a significant instruction-by-perspective interaction effect on error rate ($F_{1,37} = 6.9$, $P = .01$). Planned contrasts revealed no difference in error rate between back- and front-facing figures under the side judgment instructions ($F_{1,37} = 0.004$, $P = .95$), but under the perspective-taking instructions, error rates were higher for front- vs back-facing figures ($F_{1,37} = 14.2$, $P = .0006$). That is, error rates were higher when an imagined self-other transformation was required. There was no significant main effect of group nor any group interactions.

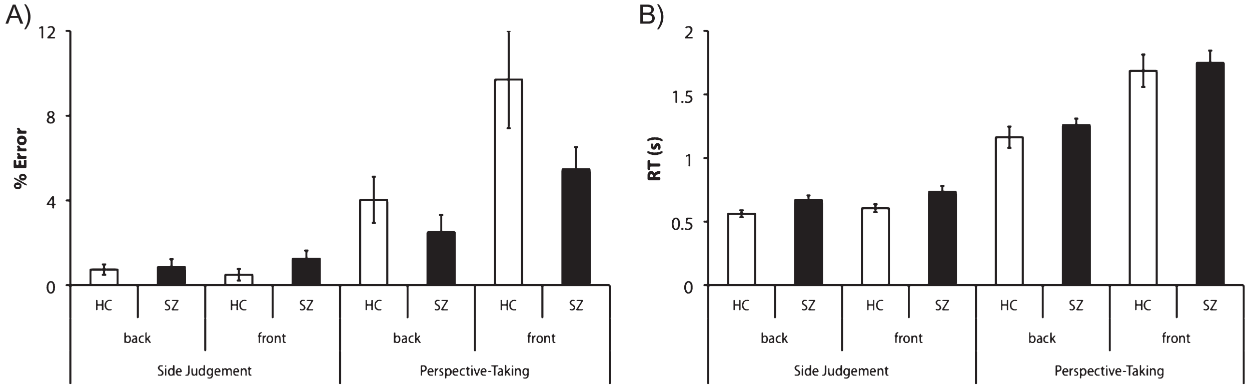

Fig. 2. (A) Error Rate and (B) RT in the People Rotation Task for Schizophrenia Patients and Healthy Controls.

RT. Results are displayed in figure 2B. There was a significant effect of instruction ($F_{1,37}$ = 123.1, $P < .0001$), with RTs being slower under the perspective-taking instruction than the side judgment instruction. There were also significant main effects of perspective ($F_{1,37}$ = 52.3, $P < .0001$) and arm position ($F_{1,37}$ = 27.9, $P < .0001$), with slower RTs when the stimulus was facing front vs back and when arms were crossed vs not crossed. Importantly, there were also significant instruction-by-perspective ($F_{1,37}$ = 35.8, $P < .0001$) and instruction-by-arm position ($F_{1,\ 37}$ = 6.9, P = .01) interaction effects on RT. Planned contrasts revealed that subjects were slower to respond when the figure was facing front than back ($F_{1,37}$ = 90.0, $P < .0001$) under the perspective-taking instructions but not the side judgment instructions ($F_{1,37}$ = 1.0, P = .31). Similarly, subjects were slower to respond when the figure's arms were crossed vs uncrossed under the perspective-taking ($F_{1,37}$ = 30.7, $P < .0001$), but not side judgment ($F_{1,37}$ = 3.3, P = .08), instruction. That is, the arm position and orientation of the stimulus figure only affected RT when the instruction required adopting the figure's perspective. There was also an arm position-by-perspective interaction effect ($F_{1,37}$ = 10.2, P = .003). Planned contrasts indicated that although participants were slower when the figure's arms were crossed vs uncrossed for both perspectives, this effect was more robust when the figure was facing front ($F_{1,37}$ = 59.3, $P < .0001$) vs back ($F_{1,37}$ = 10.1, P = .003).

There was no significant main effect of group, but there was a significant group-by-instruction-by-arm position interaction effect ($F_{1,37}$ = 4.3, P = .05). Planned contrasts revealed that under the side judgment instruction, patients were slower than controls to respond, regardless of the arm position (crossed: $F_{1,37}$ = 8.7, P = .006); not crossed: ($F_{1,37}$ = 11.1, P = .002). However, under the perspective-taking instruction, patients were slower to indicate whether the figure's right or left arm was raised only when the figure's arm was crossed ($F_{1,37}$ = 15.8, P = .0003), but not when it was uncrossed ($F_{1,37}$ = 0.1, P = .82).

Letter Rotation Task

One patient chose to discontinue the study before completing this task. Two patients and 1 control were excluded from this analysis based on poor performance; 1 patient and 1 control indicated that the letter was mirrored for almost every trial when the stimulus was rotated 180°, resulting in chance accuracy for the 180° rotation condition and another patient had an error rate of 94% in the 180° angle of rotation condition, presumably due to flipping the stimulus in the depth plan instead of rotating around the center. This strategy would result in consistently erroneous performance. Analyses were conducted on the remaining 18 controls and 17 patients. The number of trials excluded from analyses due to the subject not responding within the 10 seconds time window was low (HC: 0.61 ± 1.46; SZ: 1.06 ± 1.78) and did not differ between groups (t_{33} = 0.81, P = .42).

Error Rate. Results are displayed in figure 3A. There was a significant effect of angle of rotation on error rate, with performance becoming less accurate with increasing rotation angle ($F_{7,231}$ = 19.5, $P < .0001$). There was also a significant orientation-by-rotation angle interaction effect ($F_{7,231}$ = 5.9, $P < .0001$), with increasing rotation angle having a larger effect on error rate when the letter was displayed in normal vs mirrored orientation. Although there was no main effect of group, there was a group-by-rotation angle interaction effect ($F_{7,231}$ = 2.2, P = .03). Error rate in patients was less sensitive to rotation angle than in HCs. Planned contrasts reveal that patients made fewer errors when the stimulus was maximally rotated at 180° ($F_{1,231}$ = 12.7, P = .0004); performance was equal across groups at the other angles of rotation.

RT. Results are displayed in figure 3B. There were main effects of both orientation ($F_{1,33}$ = 35.5, $P < .0001$) and rotation angle ($F_{7,231}$ = 47.6, $P < .0001$), with slower performance for mirrored vs normally presented letters and slower performance with increasing rotation angle. There

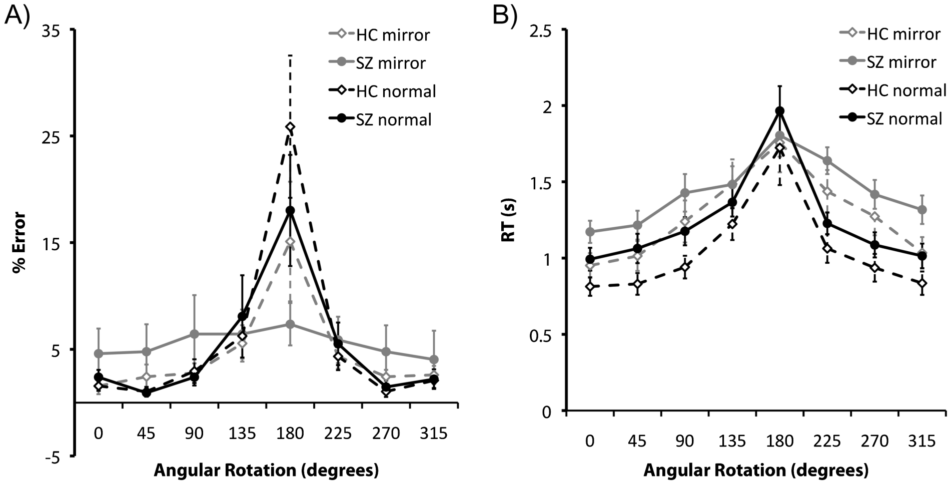

Fig. 3. (A) Error Rate and (B) RT in the Letter Rotation Task for Both Mirrored and Normal Letter Orientation in Schizophrenia Patients and Healthy Controls.

was also a significant orientation-by-angle of rotation interaction effect ($F_{7,231} = 7.6$, $P < .0001$), with increasing rotation angle having a larger effect on RT when the letter was displayed in normal vs mirrored orientation. There was no main effect of group nor any group interactions, and thus improved accuracy in the patient group cannot be explained by speed-accuracy tradeoffs.

Spatial WM

Performance on the DRT is displayed in table 1. SZ were significantly less accurate than HC (HC: 94.8 ± 7.6%, SZ: 87.7 ± 10.9%; $t_{35} = 2.29$, $P = .03$).

Discussion

In this study, we examined maintenance and manipulation components of WM in HC and SZ. Passive maintenance was assessed using a spatial DRT, and manipulation was measured using egocentric and allocentric mental rotation tasks. Consistent with our hypotheses, we found that mental manipulation of visual stimuli was spared in sample of patients in which we observed a well-replicated impairment in passive maintenance of the location of stimuli. In fact, patients were more accurate than controls on the allocentric mental rotation at the largest degree of rotation, which placed the greatest demand on mental manipulation.

These findings are contrary to previous reports that WM manipulation processes are more severely impaired than maintenance processes in SZ. One potential reason behind this discrepancy is that tasks that purport to index WM manipulation ability do not isolate these processes. For example, poor patient performance on a range of executive tasks has been used to bolster arguments for more impaired manipulation vs maintenance WM processes in SZ. However, traditional executive tasks such as the Wisconsin Card Sorting Task rely on multiple cognitive processes, making it difficult to quantify the dissociation between patient deficits related to passively maintaining information vs manipulating and updating that information. Furthermore, the *n*-back task, which requires subjects to indicate when the current stimulus matches the stimulus presented *n* steps earlier in the sequence, has been used as measure of manipulation of items in WM.[32] As others have noted,[9,33] this task conflates demands on components of WM and impaired manipulation ability in SZ does not necessarily follow from findings that patients perform disproportionately worse than controls with increasing load. Although Kim et al[9] report that WM accuracy was more affected by an added spatial transformation demand in patients, they did not include a condition in which spatial manipulation was tested without a delay period, which means their manipulation condition included maintenance demands. Thus, we argue that basic mental rotation tasks are better at isolating the manipulation processes.

Our finding of spared manipulation and impaired maintenance processes in SZ is consistent with other previous reports.[11,12] Similar to our result, Hill et al[11] also show that the difference in WM performance between patients and controls decreases with a manipulation demand. However, in our study, we found a patient benefit for manipulation of representations in WM in the condition of greatest rotation in the allocentric mental rotation task. This finding of greater mental rotation accuracy in patients vs controls is novel.

Although previous studies have found spared mental rotation ability in SZ,[17,18,34] ours is the first study to report more accurate mental rotation in patients vs controls. One potential reason for this is that in prior studies, patients and controls were not matched for IQ. Both verbal and performance IQ have been found to correlate with mental rotation ability,[35] and in the current study, patients and controls were matched for premorbid estimates of intelligence.

Quee et al[12] also used mental rotation as an index of WM manipulation in a delayed match-to-sample task. In the condition in which there was a minimal delay between target and probe (0.5 seconds), although patients were not disproportionately impaired when required to manipulate the stimulus by rotating it 180° vs passively maintain, they were still impaired in the manipulation condition relative to controls. With regard to this study, possible differences include their use of a fairly complex Chinese character, a limited encoding time, and a delay period, albeit brief, following target presentation. These parameters are important given findings that encoding and early parts of maintenance may be particularly impaired in patients.[1]

Our finding of more accurate allocentric mental rotation in the 180° condition in SZ can be considered in light of work on mental imagery. Mental imagery is the process of actively generating and controlling internal representations that reconstruct former perceptual experiences,[36] and mental rotation paradigms have been used to investigate the control of mental images. Although controversial, there are findings that patients with SZ report better mental image generation than HCs,[37,38] but these findings are not consistent.[39] Furthermore, behavioral studies examining patient performance on cognitive tasks that purport to rely on mental imagery have not revealed a patient advantage.[40,41] Still, the results of this study indicate a need for further examination of mental imagery in SZ, its relationship to WM, and consideration of tasks employed to examine these processes.

But how do we reconcile findings of impaired passive maintenance with intact, if not superior, mental rotation ability in the same group of patients? Even the mental rotation task is not a pure test of manipulation, and the spatially updated representations must still be maintained online.[13,41] Although speculative, 1 possible interpretation of these results is that the task of having to mentally rotate an object in WM focuses attention to the internal representation of that object. Previous research has shown that orienting spatial attention to internal representations facilitates accurate maintenance of these representations, which is argued to reflect spatially specific enhancement of these representations.[42] The 2 mental rotation tasks in the current study involve updating an internal representation of one's own body in space or a 2-D letter on the screen. Potentially, performing a spatial operation on these representations enhances their online maintenance. So, if impaired passive maintenance in SZ is at least partly due to failure to allocate attention to the relevant features of the internal representation,[1] spared manipulation of the internal representation (when maintenance of these representations over a delay is not required) might be observed due to increased attention allocation to the stimulus in order to perform the spatial transformation. That is, manipulation could facilitate maintenance equally, if not more, in patients. Future studies might investigate this hypothesis by devising a task in which subjects are required to manipulate a stimulus in WM in for the entire duration of a delay period. Based on the findings of the current study and those of Griffin and Nobre,[42] we might predict that manipulating contents of WM during a delay would enhance spatial attention to these stimuli and that patients would benefit as much, if not more, than HCs. Thus, requiring continuous manipulation of a stimulus might be an effective strategy for improving WM performance in patients.

However, the current findings should be considered in light of several limitations. First, the sample size consisted of a relatively small group of medicated patients, and the role of neuroleptic treatment on mental rotation performance is unknown. Furthermore, given that the patients consisted of a fairly high functioning group of outpatients who were matched with controls for premorbid intellectual functioning, this sample might not be representative of all individuals with SZ. With regard to the experimental paradigm, we cannot rule out that differences in the pattern of performance on the DRT and mental rotation tasks were due to stimulus-specific factors (ie, single dots vs human bodies and letters). However, we should note here that our objective was not to directly compare performance on these 2 tasks. Rather, the goal of this study was to examine mental manipulation ability in schizophrenic patients who already are known to have spatial WM deficits. That is, given this deficit in maintaining spatial information during a delay, how well do patients manipulate information when the maintenance demand is minimal? Regardless, we do not think that a confounding effect of stimulus properties can account for our results. Both spatial and object WM deficits have been consistently observed in SZ using simple shapes, familiar objects, and letters.[20,43–47] Thus, it would be highly unlikely that we would observe spared and, in some conditions, better performance on the mental rotation tasks simply as a result of stimulus characteristics. Finally, the extent to which these findings of spared, and sometimes superior, manipulation ability in SZ patients generalizes to other tasks is unclear. Furthermore, visual information was on screen during the entire response period, so we do not know whether group differed in the extent to which they relied on the available perceptual information. However, the novel findings from the current study should provide a basis for further investigation of manipulation of mental representations in SZ and its relationship to WM performance.

In conclusion, the current study set out to examine maintenance and manipulation of items in WM in patients with SZ. We found intact manipulation ability in SZ indexed by performance on mental rotation tasks;

in fact, patients outperformed controls on an allocentric mental rotation task at the largest degree of mental rotation and showed a nonsignificant pattern of improved accuracy on an egocentric mental rotation task. However, the same group of patients showed impairments in passive maintenance of spatial information. These findings indicate a spared subcomponent of WM in SZ.

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