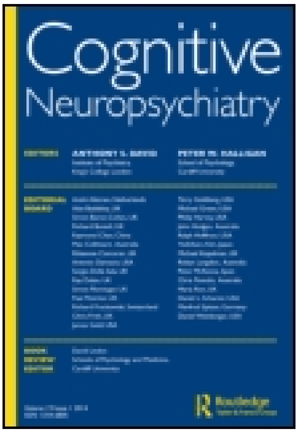
This article was downloaded by: [VUL Vanderbilt University]
On: 03 January 2014, At: 13:56
Publisher: Routledge
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Cognitive Neuropsychiatry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/pcnp20

Visuospatial imagery and working memory in schizophrenia

Natasha L. Matthews[ab], Kathleen P. Collins[b], Katharine N. Thakkar[b] & Sohee Park[b]

[a] The Queensland Brain Institute, The University of Queensland, Australia

[b] Department of Psychology, Vanderbilt University, Nashville, TN, USA

Published online: 24 May 2013.

To cite this article: Natasha L. Matthews, Kathleen P. Collins, Katharine N. Thakkar & Sohee Park (2014) Visuospatial imagery and working memory in schizophrenia, Cognitive Neuropsychiatry, 19:1, 17-35, DOI: 10.1080/13546805.2013.779577

To link to this article: http://dx.doi.org/10.1080/13546805.2013.779577

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Cognitive Neuropsychiatry, 2014
Vol. 19, No. 1, 17–35, http://dx.doi.org/10.1080/13546805.2013.779577

Routledge
Taylor & Francis Group

Visuospatial imagery and working memory in schizophrenia

Natasha L. Matthews[a,b], Kathleen P. Collins[b], Katharine N. Thakkar[b] and Sohee Park[b]*

[a]*The Queensland Brain Institute, The University of Queensland, Australia;* [b]*Department of Psychology, Vanderbilt University, Nashville, TN, USA*

(*Received 13 May 2012; accepted 20 February 2013*)

Introduction. The ability to form mental images that reconstruct former perceptual experiences is closely related to working memory (WM) ability. However, whereas WM deficits are established as a core feature of schizophrenia, an independent body of work suggests that mental imagery ability is enhanced in the disorder. Across two experiments we investigated mental imagery in schizophrenia and its relationship with WM.
Methods. In Experiment 1, individuals with schizophrenia (SZ: $n = 15$) and matched controls (CO: $n = 14$) completed a mental imagery generation and inspection task and a spatial delayed-response WM task. In Experiment 2, SZ ($n = 16$) and CO ($n = 16$) completed a novel version of the mental imagery task modified to increase WM maintenance demand.
Results. In Experiment 1, SZ demonstrated enhanced mental imagery performance, as evidenced by faster response times relative to CO, with preserved accuracy. However, enhanced mental imagery in SZ was accompanied by impaired WM as assessed by the delayed-response task. In Experiment 2, when WM maintenance load was increased, SZ no longer showed superior imagery performance.
Conclusions. We found evidence for enhanced imagery manipulation in SZ despite their WM maintenance deficit. However, this imagery enhancement was abolished when WM maintenance demands were increased. This profile of enhanced imagery manipulation but impaired maintenance could be used to implement novel remediation strategies in the disorder.

Keywords: mental imagery; schizophrenia; working memory

Introduction

Mental imagery is the process by which we actively generate and control internal representations that reconstruct former perceptual experiences (Kosslyn, 1980). This ability can be fractionated into sub-processes that are responsible for the active generation, inspection, and manipulation of internal representations (Kosslyn, 1980). Mental images are sequentially generated by activating stored memories of parts of these images, and integrated to construct whole images (Kosslyn, 1988).

Many studies report enhanced vividness of mental imagery in schizophrenia based on subjective report (Bocker, Hijman, Kahn, & De Haan, 2000; Mintz & Alpert, 1972; Sack, van de Ven, Etschenberg, Schatz, & Linden, 2005). Traditionally, enhanced mental imagery ability in schizophrenia has been investigated in relation to

*Corresponding author. Email: Sohee.park@vanderbilt.edu

© 2013 Taylor & Francis

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

the experience of hallucinations. Studies showing a relationship between vividness of mental images and the presence of hallucinations (Bocker et al., 2000; Mintz & Alpert, 1972; Sack et al., 2005) have led some to argue that hallucinatory experiences may arise from vivid mental images that are not perceived as self-generated (Bentall, 1990). Other groups, however, have failed to find a relationship between mental imagery and clinical symptoms (Aleman, Bocker, Hijman, de Haan, & Kahn, 2003; Oertel et al., 2009; Sack et al., 2005), leading them to argue that enhanced mental imagery may represent a potential trait marker of the disorder (Sack et al., 2005).

Comparatively little research has been conducted on putative consequences of enhanced mental imagery for cognitive ability in schizophrenia. Mental imagery is crucial to the performance of many tasks that require participants to generate, store, and manipulate internal representations. Indeed, it is well established that mental imagery is closely related to working memory (WM) ability. In Baddeley's model (1992, 2003), working memory is comprised of a limited capacity attentional control system (the *central executive*) that is subserved by two modality-specific buffer systems that maintain and manipulate visual (the *visuospatial sketchpad*) and auditory/verbal (the *phonological loop*) information. These buffer storage systems are assumed to be intricately involved in visual and auditory mental imagery, respectively (Kosslyn, 1980). Evidence for this involvement comes, in part, from dual task paradigms in which subjects are asked to perform a task that taps the resources and capacity of the modality-specific subsystems, which reduces the subjects' ability to perform imagery tasks in the matching modality. For example, performing a task that taps the capacity of the visuospatial sketchpad selectively impairs one's ability to form a concurrent mental image of a previously presented visual stimulus (Baddeley & Andrade, 2000). In addition, there is evidence that visual WM and visual imagery both rely on depictive representations that share the same format (Borst, Ganis, Thompson, & Kosslyn, 2012). Borst et al. (2012) argue that this is an important requirement for demonstrating a degree of functional overlap between the two abilities. Visual imagery and visual WM also share overlapping neural circuitry (Slotnick, Thompson, & Kosslyn, 2011), and evidence suggests that impairments in these two abilities not only covary (Briggs, Raz, & Marks, 1999; Bruyer & Scailquin, 2000), but that visual WM performance in healthy populations can be predicted by the strength of visual mental imagery (Keogh & Pearson, 2011).

It is well established that deficits in WM are a core feature of schizophrenia (Lee & Park, 2005). The WM deficit is present regardless of clinical state (Haenschel et al., 2009; Park, Puschel, Sauter, Rentsch, & Hell, 1999; Reilly, Harris, Keshavan, & Sweeney, 2006), observed in healthy first-degree relatives (Glahn et al., 2003; Myles-Worsley & Park 2002; Park, Holzman, & Goldman-Rakic, 1995), and is associated with abnormal frontoparietal cortical activity (Barch & Csernansky, 2007; Driesen et al., 2008; Lee, Folley, Gore, & Park, 2008). Given evidence for the close association between WM ability and mental imagery, findings of increased vividness of mental imagery in schizophrenia is at odds with evidence for impaired WM ability in the disorder.

The aim of the present study is to reconcile this apparent dissociation between WM and mental imagery ability. One possibility is that while individuals with schizophrenia produce mental images that are rated as subjectively more vivid, patients may be less able to strategically control these images or the images may contain less precision when interrogated using objective cognitive behavioural

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

methods. Few studies have employed such methods to explore imagery in schizophrenia, with mixed results. David and Cutting (1992) found individuals with schizophrenia to be unimpaired on an imagery-based size judgement task that required participants to generate a mental image of an object and determine whether it was larger or smaller than a cat. Aleman, de Haan, and Kahn (2005), however, found individuals with schizophrenia to be impaired on an object imagery task in which participants were required to generate mental images of a set of items and determine which item differed from the group in visual form. Such tasks do not allow us to draw conclusions about the precision of mental images, as the degree to which other cognitive processes, such as semantic knowledge, are involved is unclear. The most sensitive tests of mental imagery ability in schizophrenia to date have come from investigations of the manipulation of visual imagery using mental rotation tasks. Classically, speed and accuracy decrease as a function of the degree of mental rotation on these tasks (Shepard & Metzler, 1971). De Vignemont et al. (2006) found that mental rotation ability was preserved in schizophrenia, as evidenced by the absence of a greater performance cost of increased rotation. Thakkar and Park (2012) investigated the manipulation and maintenance components of spatial WM and found that schizophrenia patients showed superior manipulation ability, as assessed by more accurate mental rotation in the most difficult condition compared with healthy controls. However, the same participants showed deficits in a spatial delayed-response task, which probed the ability to maintain representations in WM. These results suggest enhanced visuospatial imagery manipulation in the presence of WM maintenance deficits.

Overall, the results of empirical studies of mental imagery point to intact or even enhanced imagery ability in schizophrenia, but no study has examined subjective vividness, imagery generation, image inspection, and WM ability in the same group of patients. Cognitive deficits represent a fundamental feature of schizophrenia and are recognised as an important predictor of functional outcome in the disorder (Green, Kern, Braff, & Mintz, 2000). Identifying and understanding domains of preserved cognitive abilities in schizophrenia will provide unique and powerful avenues in the process of remediation of cognitive functions.

Experiment 1: Mental Imagery Generation and Inspection

The aim of Experiment 1 was to investigate visuospatial imagery generation and inspection in schizophrenia using a task developed by Kosslyn and colleagues (Kosslyn, Cave, Provost, & von Gierke, 1988) and adapted for use in clinical populations (Zarrinpar, Deldin, & Kosslyn, 2006). This task has been shown to provide a reliable and sensitive measure of imagery performance. Performance on this task was compared to subjective ratings of the vividness of mental imagery and with spatial WM maintenance ability.

Methods

Participants

Fifteen outpatients with schizophrenia were recruited from a private psychiatric facility in Nashville, TN. Diagnoses were confirmed using the structured clinical interview for DSM-IV (SCID-IV: First, Spitzer, Gibbon, & Williams, 1997). All patients were taking antipsychotic medication at the time of testing (five on risperidone, three on olanzapine, three on quetiapine, one on paliperidone, one on thiothixene, and one on clozapine). Fourteen healthy control participants with no history of DSM-IV Axis I disorder in themselves or their first-degree relatives were recruited from the same city. The two groups (individuals with schizophrenia—SZ; matched controls—CO) were matched for age, education, IQ (Wechsler Abbreviated Scale of Intelligence, WASI—Wechsler, 1999; and National Adult Reading Test, NART—Nelson, 1982), sex, and handedness (Oldfield, 1971; Table 1). All had normal or corrected-to-normal vision. Exclusion criteria were as follows: substance use within the past 6 months, neurological disorders, or history of head injury. All participants provided written informed consent in accordance with the Declaration of Helsinki and were compensated for their participation. The Vanderbilt University Institutional Review Board approved the study protocol.

Design and procedure

Clinical measures. Current symptoms ratings were obtained on the day of testing using the Brief Psychiatric Rating Scale (BPRS; Overall & Gorham, 1962), the Scale for the Assessment of Positive Symptoms (SAPS; Andreasen, 1984), and the Scale for the Assessment of Negative Symptoms (SANS; Andreasen, 1983) (Table 1).

Imagery generation and inspection task (for full details see Zarrinpar et al., 2006). The imagery task consisted of two phases: a training phase and a testing phase. During the training phase, participants learned the way in which four uppercase block letters (H, J, S, U) fell onto a 4 × 5 grid (Figure 1a). These four letters were shown three times each on a computer screen, and participants were then asked to draw the letters onto a blank grid until they could draw them without error. During the testing phase, participants completed both a mental imagery and a perceptual control condition. Trials were blocked, and the two conditions were counterbalanced for order. There were 16 trials per condition. Stimulus presentation and response collection were

Table 1. Demographic and clinical information for individuals with schizophrenia (SZ) and healthy control (CO) participants for Experiment 1. (means, with *SD* in parentheses)

	CO (n = 14)	SZ (n = 15)
Age (years)	40.00 (9.5)	41.3 (8.54)
Sex	3 M, 11 F	9 M, 6 F
IQ (WASI)	98.8 (14.3)	101.1 (24.0)
IQ (NART)	103.5 (7.21)	104.7 (10.9)
Years of education	15.38 (2.47)	14.33 (2.09)
Handedness	13 right handers 1 left hander	12 right handers 3 left handers
Duration of illness (years)	—	21.73 (8.04)
BPRS	—	14.00 (9.36)
SAPS	—	17.67 (3.84)
SANS	—	34.53 (18.57)

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

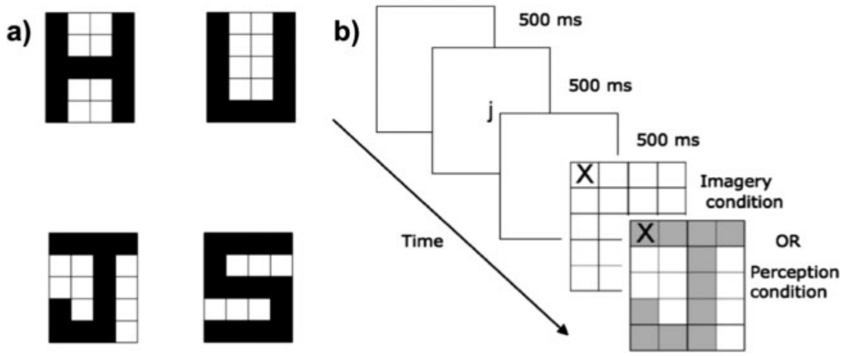


Figure 1. Task design for Experiment 1, adapted from Kosslyn et al. (1988). (a) Letter stimuli learnt by participants in the practice stage and then imaged during the testing phase. (b) Procedure for imagery and perception conditions. Participants were cued with a lower case letter to form a mental image of one of the four previously learnt uppercase letters. In the imagery condition participants determined if the probe "X" fell on the imaged letter. In the perception control condition participants determined in the probe fell on a light grey letter.

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

controlled with Matlab, using the Psychophysics Toolbox extensions (Brainard, 1997).

In the mental imagery condition, participants were cued for 500 ms with a lowercase letter (h, j, s, u), to create a mental image of one of the four previously learned uppercase block letters. Following the cue, participants were presented with a blank 4 × 5 grid onto which they were to overlay the mental image of the cued letter. A probe (X) was always presented somewhere on the grid in different locations across trials. Participants indicated via keypress if the probe fell on a grid square that overlapped with the imagined letter by pressing the YES or NO key. The probe remained on the screen until the participant made a response or a 10 s time-out period had expired.

The perceptual control condition was identical to the imagery condition, except that a faint grey letter was presented on the grid. Participants responded via keypress whether or not the probe fell on the grey letter (Figure 1b).

Accuracy and response time (RT) were measured. Given the relative ease of the task, RT was the dependent measure of greatest interest. Across both the perceptual and imagery conditions, the complexity of the target letter and the position of the probe on the grid were varied. Letters could contain three segments (simple) or four or more segments (complex). During the testing phase, the probe (X) could occur in either an early or late position. In early trials, the probe was placed in a cell that is typically covered first when physically writing the letter. In late trials, the probe was placed in a cell that is typically covered last when writing the letter. The manipulation of the complexity of the stimuli and the position of the probe allowed us to study the strategy used for the task. If the stimulus complexity affected imagery performance, we would predict longer RTs for complex stimuli because it would take more effort and time to generate them (Kosslyn et al., 1988). If participants were mentally drawing the letter on the grid, we would expect to see faster RTs for "early" compared to "late" probes. On the other hand, if they were imagining the whole letter at once, RT would not be affected by the probe location (Kosslyn et al., 1988).

Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973). This questionnaire was administered as an interview. Participants were asked to imagine different scenes and to rate the vividness of various aspects of their mental image on a 5-point scale with 1 representing the most vivid imagery (as clear as normal vision) and 5 representing the least vivid image (no image at all). Participants were instructed to imagine four scenes and answer four questions about each for a total of 16 items. All items were rated with the eyes open and then repeated with the eyes closed.

Spatial Working Memory (SWM) task. The delayed-response task described in Park et al. (1999) was used to assess SWM performance on a computer fitted with a touch screen. On each trial a small target circle was flashed in the periphery for 400 ms, followed by a 10 s delay, after which the participant was asked to indicate the location of the target by touching the remembered location. The experiment consisted of 48 trials. Accuracy and RT to touch the screen were recorded. This task measures the ability to maintain spatial locations in WM.

Results

Mental imagery

Accuracy. Accuracy was investigated in a 2 (group: SZ, CO) × 2 (task: imagery, perceptual control) × 2 (complexity: simple, complex) × 2 (position: early, late) ANOVA. Accuracy was high in both groups, and there was no significant difference between the groups in either the imagery condition (CO: $M = 96.4\%$, $SD = 4.04$; SZ: $M = 94.17\%$, $SD = 3.17$), $F(1, 27) = 1.56$, $p = .129$, or the perceptual control condition (CO: $M = 98.66\%$, $SD = 2.66$; SZ: $M = 95.42\%$, $SD = 11.12$), $F(1, 27) = 1.09$, $p = .292$.

Response time. RTs on correct trials were compared in a 2 (group: SZ, CO) × 2 (task: imagery, perceptual control) × 2 (complexity: simple, complex) × 2(position: early, late) ANOVA. There was a significant main effect of the task, $F(1, 27) = 51.56$, $p < .001$, with faster RTs overall in the perceptual control than in the imagery condition. Most importantly, there was a significant interaction between task and group, $F(1, 27) = 4.12$, $p = .05$. SZ were significantly faster than CO in the imagery condition, but not in the perceptual control condition (Figure 2).

There was also a significant main effect of complexity, $F(1, 27) = 14.3$, $p = .001$, with faster RTs for simple than complex letters. However, there was a significant task-by-complexity interaction, $F(1, 27) = 7.17$, $p = .012$, such that RTs differed significantly between simple and complex letters in the imagery, $F(1, 27) = 13.20$, $p = .001$, but not in the perceptual control, $F(1, 27) = 1.97$, $p = .172$, condition.

There was also a significant main effect of probe position, $F(1, 27) = 7.17$, $p = .012$. RTs were faster for probes that occurred early rather than late, suggesting that participants employed a mental re-drawing strategy when generating mental images. There were no other significant main effects or interactions.

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

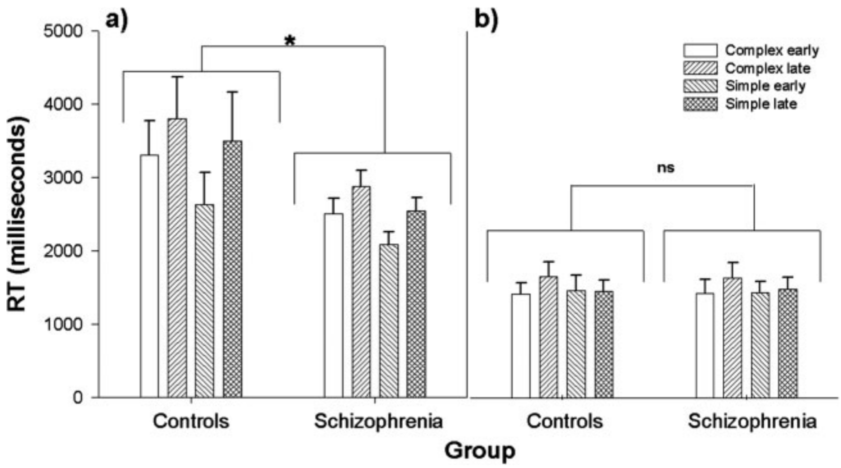


Figure 2. Response time (in milliseconds) for (a) the imagery condition and (b) the perceptual control condition in Experiment 1. *$p < .05$.

Spatial working memory

SZ ($M = 72.92\%$, $SD = 25.82$) were significantly less accurate than CO ($M = 93.43\%$, $SD = 6.74$), $F(1, 27) = 2.66$, $p = .009$, on the spatial working memory task; however, there were no significant group differences in RT.

VVIQ

There were no significant differences in VVIQ ratings between SZ and CO, with the two groups reporting similar subjective vividness of mental images with eyes open (CO: $M = 25.1$, $SD = 6.16$; SZ: $M = 31.3$, $SD = 11.17$), $F(1, 27) = 1.64$, $p = .094$, and closed (CO: $M = 25.00$, $SD = 5.07$; SZ: $M = 30.03$, $SD = 11.04$), $F(1, 27) = 1.48$, $p = .124$.

Correlations among measures

There were no significant correlations between VVIQ scores and performance on any of the imagery task conditions in either group. Moreover, there was no correlation between WM and imagery task accuracy or RT in either group. Clinical symptoms ratings and normalised medication dose (Woods, 2003) did not correlate with any of the task measures.

Discussion

We replicated the complexity and position effects in imagery previously described (Kosslyn et al., 1988; Zarrinpar et al., 2006), namely that RTs were slower for complex than for simple letters and that early probes were responded to more quickly than later probes, suggesting that participants were using a redrawing strategy. These effects did not interact with diagnosis thus demonstrating that, regardless of diagnosis, participants were able to generate and inspect mental images sequentially

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

in real time using similar strategies. In other words, schizophrenia patients seem to be able to manipulate and control mental representations.

The most important and surprising finding is that individuals with schizophrenia showed enhanced mental imagery performance compared with controls, as evidenced by significantly faster RTs in the imagery condition. There was no difference in accuracy between groups, suggesting that faster RTs in patients were not due to a speed–accuracy trade-off. Further, this RT facilitation for schizophrenia was not evident in the perceptual control condition, suggesting a selective advantage for the imagery component, and not an overall speeding of responses. Since individuals with schizophrenia are generally slower than controls on almost any task requiring manual responses (Gale & Holzman, 2000), this observed RT facilitation for imagery is unexpected and provides strong support for enhanced mental imagery.

The two groups did not differ on the VVIQ. Thus, patients from this sample did not report generally enhanced vividness of their imagery experience. Despite their superior imagery performance, individuals with schizophrenia showed a deficit in visuospatial WM maintenance. Thus, active imagery generation and inspection ability does not seem to aid or support WM maintenance in schizophrenia.

These findings provide evidence for dissociation between mental imagery and WM in schizophrenia. However, the imagery task placed almost no demand on the maintenance of mental representations in WM, because the interval between the cue and the probe was only 500 ms. Enhanced visuospatial imagery in this experiment suggests that individuals with SZ are able to deploy and move spatial attention across internal representations when there is almost no WM maintenance demand. Thakkar and Park (2012) reported that individuals with schizophrenia are better than controls in the manipulation of internal representations (mental rotation). Thus, taken together, our results indicate that individuals with schizophrenia are better than healthy participants in generating, inspecting and moving mental images in the mind's eye when WM maintenance demands are negligible. In contrast, a study by Cannon et al. (2005) reported that individuals with schizophrenia are worse than control subjects when they have to simultaneously maintain *and* manipulate internal representations. Thus, a remaining question is whether the enhanced imagery ability we observed in schizophrenic patients dissipates with increasing WM maintenance demand.

Lastly, we consider the potential effects of using familiar letters in this experiment. Letters are highly learned stimuli and in addition, subjects were given extensive practice trials to become familiarised with the visual aspects of these letters. Generating mental images from stored representations in long-term memory (LTM) as in this case, may not burden the "central executive" component of the WM system. However, when new mental images must be generated from unfamiliar, novel stimuli, there are no stored representations in LTM to access, and consequently, there is a greater burden on the central executive during image generation. The aims of Experiment 2 were twofold. We hypothesised that increasing the WM maintenance load by adding a delay between stimulus presentation and imagery generation would impair the performance of individuals with schizophrenia. A second aim was to compare the effects of familiarity of the stimuli on imagery performance to better understand the difference between imagery generation with or without access to LTM representations. To test the second hypothesis, we introduced unfamiliar shape

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

stimuli and compared imagery generation ability for familiar letters with that for novel shapes.

Experiment 2: Visuospatial Imagery Generation and Inspection While Maintaining Internal Representations

The aim of Experiment 2 was to further examine the effect of increasing WM demands on mental imagery generation and inspection by increasing the delay between cue and probe in a letter imagery task and testing the effects of familiarity on imagery generation by introducing novel shapes.

Methods

Participants

Sixteen SZ and 16 CO participated in Experiment 2. The same criteria for diagnosis and exclusion used in Experiment 1 were applied. All patients were taking antipsychotic medication at the time of testing (eight risperidone, two olanzapine, two clozapine, three quetiapine, one ziprasidone). The two groups were matched for age, IQ, education, sex, and handedness (Table 2). All participants provided written informed consent in accordance with the Declaration of Helsinki and were compensated. The Vanderbilt University Institutional Review Board approved this study protocol. Ten individuals with schizophrenia and nine healthy control subjects in this study also participated in Experiment 1.

Design and procedure

The same clinical and demographic measures were obtained as in Experiment 1.

Letter and shape imagery generation and inspection task. The imagery task from Experiment 1 was modified in order to increase the WM maintenance demands of the task, and to investigate the effect of the familiarity of target stimuli on imagery performance. Specifically, four important changes were made. (1) In Experiment 2,

Table 2. Demographic and clinical information for individuals with schizophrenia (SZ) and healthy control (CO) participants for Experiment 2. (means, with *SD* in parentheses)

	CO (n = 16)	SZ (n = 16)
Age (years)	39.00 (8.43)	38.70 (8.30)
Sex	6 M, 10 F	10 M, 6 F
IQ (WASI)	106.8 (11.2)	98.4 (14.9)
IQ (NART)	107.4 (6.71)	103.3 (9.7)
Years of education	15.46 (2.53)	13.31 (2.44)
Handedness	15 right handers 1 left hander	13 right handers 3 left handers
Duration of illness (years)	—	17.13 (7.98)
BPRS	—	14.18 (8.56)
SAPS	—	14.00 (15.93)
SANS	—	28.63 (13.00)

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

the task consisted of two conditions: a letter condition, which used familiar letter stimuli, and a shape condition, which used unfamiliar block shapes (see Figure 3a). These unfamiliar stimuli were used to examine the ability of participants to generate images of new percepts. The shapes were matched to the letters in complexity (number of segments) and in size (number of cells covered). (2) The training phase was removed to ensure that the shape stimuli remained unfamiliar during the testing phase. (3) Since we demonstrated in Experiment 1 that SZ did not differ from CO on the perceptual control task, this condition was removed. (4) A 3-s delay was introduced between the cue and the probe in order to increase WM maintenance demands (see Figure 3b).

The procedure was identical for the shape and the letter conditions (see Figure 3b) and followed a similar structure to the imagery task used in Experiment 1. On each trial, participants were presented with one of the eight possible block letters or shapes for 2 s on the same 4×5 grid as used in Experiment 1. Participants were instructed to study the stimulus, as they would be required to form a mental image of it at the end of the trial. Participants were then presented with a fixation screen for 3 s. After the delay the participant was shown a blank grid with a probe (X) in one of the cells. The participant formed a mental image of the stimulus onto the grid and indicated via a keypress whether or not the probe fell on the imagined stimulus. Accuracy and reaction time were measured. Shape and letter conditions were presented separately in blocks of 32 trials, and, and the order of the conditions was counterbalanced across participants.

As in Experiment 1, the stimuli were classified as simple or complex according to the number of segments in the stimulus. Four stimuli in each condition were classified as simple (three segments) and four as complex (four or more segments). Probe position was not a consideration in Experiment 2 since the shapes were unfamiliar and did not follow a standard drawing pattern.

Spatial working memory task. In Experiment 1, responses on the spatial WM task were acquired using a touch screen, which made the comparison of RTs across the imagery and WM tasks problematic. The SWM task in Experiment 2 used keypresses

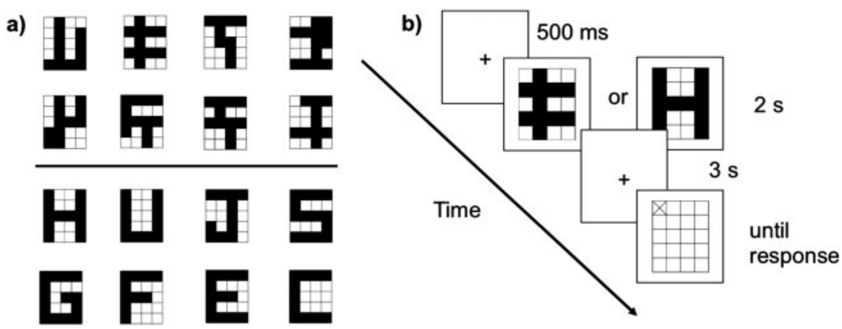


Figure 3. Task design for Experiment 2. (a) Set of stimuli presented to participants in Experiment 2, in separate blocks; familiar letters (lower panel) and unfamiliar shapes (upper panel). (b) Procedure for Experiment 2. Participants were presented with a letter or shape stimulus (in separate blocks) for 2 s. After a 3-s delay participants were presented with a blank grid and asked to determine a mental image formed of the letter or shape stimulus overlapped with a probe "X".

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

to record responses. The procedure was identical to that from Experiment 1, with a few modifications. The target presentation time was 300 ms and the delay period was 8 s. After the delay period, participants were instructed to indicate the location using one of eight possible key presses that corresponded with the eight possible target locations. Accuracy and RT were recorded.

Results

Imagery task

Accuracy. Accuracy was investigated in a 2 (group: SZ, CO) × 2 (task: letter, shape) × 2 (complexity: simple, complex) ANOVA. Overall accuracy was higher on the familiar letter task than the unfamiliar shape task, $F(1, 30) = 88.88$, $p < .001$. In addition, SZ were, overall, less accurate than CO, $F = (1, 30) = 5.152$, $p = .031$. However, there was also a significant interaction between group and task, $F(1, 30) = 6.45$, $p = .016$. The accuracy results for the letter imagery condition were consistent with the findings in Experiment 1. Accuracy was high in both CO ($M = 92.96\%$, $SD = 6.30$) and SZ ($M = 91.77\%$, $SD = 7.56$), and there was no significant difference between the two groups for familiar letters, $F(1, 30) = 0.23$, $p = .64$. For the shape imagery task, however, CO participants were significantly more accurate ($M = 81.05\%$, $SD = 7.08$) than SZ ($M = 71.05\%$, $SD = 11.89$), $F(1, 30) = 8.23$, $p = .007$. Thus, SZ were less accurate than CO in generating and inspecting unfamiliar images (Figure 4).

There was also a significant main effect of complexity, $F(1, 30) = 14.50$, $p = .001$, with accuracy higher overall for simple than for complex stimuli. However, there was also a significant task-by-complexity interaction, $F(1, 30) = 0.05$, $p = .004$, such that accuracy was better for simple stimuli in the shape, $F(1, 30) = 19.50$, $p < .001$, but not in the letter, $F(1, 30) = 2.09$, $p = .158$, condition (Figure 4).

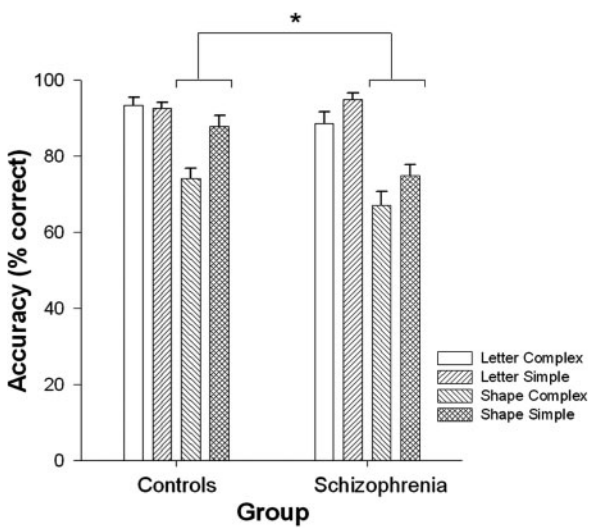


Figure 4. Accuracy (percentage correct) for the letter and shape mental imagery conditions in Experiment 2. *$p < .05$.

Response time. RTs on correct trials were compared in a 2 (group: SZ, CO) × 2 (task: letter, shape) × 2 (complexity: simple, complex) ANOVA. There was a significant main effect of task, $F(1, 30) = 5.15$, $p = .031$, with RTs slower overall for the familiar letter task ($M = 2954$, $SD = 1912.11$) than the shape task ($M = 2345$, $SD = 1249.85$). Unlike in Experiment 1, however, there were no significant main effect group for the letter (HC: $M = 2377$, $SD = 987.65$; SZ $M = 3530$, $SD = 2423.03$) or shape task (HC: $M = 2172$, $SD = 639.48$; SZ $M = 2518$, $SD = 1659.9$) and no interactions, suggesting that the two groups did not differ in RT on either imagery task.

Spatial WM task

Accuracy. Participants in the SZ group were significantly less accurate ($M = 87.86$, $SD = 12.28$), than those in the CO group ($M = 96.83$, $SD = 6.79$) on the spatial WM task, $F(1, 30) = 2.95$, $p = .016$.

Response time. Participants in the SZ group had significantly slower RTs ($M =$ 2233.4 ms, $SD = 110.5$) compared with the CO ($M = 1509.5$ ms, $SD = 606.5$), $F(1, 30) = 2.49$, $p = .019$, on the WM task.

Correlations among measures

First, correlations were performed between overall accuracy and RT on the shape and letter imagery tasks and performance on the spatial WM task. There was a significant positive correlation between spatial WM RT and shape imagery RT in CO, $r = .56$, $p = .030$, suggesting that WM and imagery ability are associated. In SZ, there was no significant relationship between measures of WM and imagery.

Correlational analyses were also performed between RT and accuracy on the imagery task and clinical symptoms and medication dose in SZ. There were significant negative correlations between SANS total score and imagery accuracy for both shapes, $r = -.61$, $p = .005$, and letters, $r = -.50$, $p = .050$. SZ with more severe negative symptoms tended to show reduced imagery accuracy. There were no correlations with positive symptoms and no correlation with medication dose.

Discussion

The aim of Experiment 2 was to investigate the effect of increasing WM demands on mental imagery generation and inspection. There were two major differences in the design of Experiments 1 and 2. First, a 3-s delay period was introduced between stimulus presentation and the presentation of the probe. This delay forced subjects to maintain mental images in order to perform the imagery inspection task and allowed us to investigate the role of WM maintenance on imagery performance. Second, the effect of stimulus familiarity on mental imagery performance was investigated through the introduction of novel shape stimuli and the removal of practice trials. The absence of practice trials forced subjects to generate mental images from new percepts for the shape stimuli. Although no practice was given for the letter stimuli in Experiment 2, these stimuli remain overlearned and highly familiar.

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Therefore, the effects of familiarity in imagery generation could be tested by contrasting performance for the letter and shape stimuli.

We hypothesised that the addition of a WM maintenance demand would reduce performance on the mental imagery task, especially in individuals with schizophrenia. There were no significant differences between individuals with schizophrenia and controls on reaction time measures of imagery performance in Experiment 2, for either the letter or shape task, indicating that WM maintenance demands seem to abolish the imagery enhancement effect for individuals with schizophrenia seen in Experiment 1. However, interestingly, patients performed just as accurately as control participants on the letter task. This suggests that imagery manipulation ability was still intact in individuals with schizophrenia for familiar visual stimuli, even when working memory maintenance demands were introduced.

Stimulus familiarity influenced the accuracy of imagery performance, with both groups performing less accurately when required to generate mental images of unfamiliar shape stimuli compared to familiar letter stimuli. However, this effect was more pronounced in individuals with schizophrenia, who differed from controls in the accuracy of mental imagery performance for the shape, but not the letter task. Generating new imagery is thought to require greater involvement of the central executive (Logie, 1995); thus, the shape condition placed a greater burden on working memory than the letter condition. The reduced WM capacity of individuals with schizophrenia may further diminish the resources available to generate and inspect novel mental images, resulting in the greater deterioration of performance in the unfamiliar shape condition.

Overall reaction times were longer for the letter (familiar) than for the shape (unfamiliar) imagery task, whereas accuracy was better for letters than shapes. This might indicate a speed–accuracy trade-off or different strategies used to perform familiar versus novel image generation. Generic mental categories of letters are accessible from long-term memory. Access to long-term memory representations could have supported the generation and inspection of the images during this task for both groups. Such a strategy would increase the accuracy of task performance, but would have also taken longer because subjects are presumably relying on a redrawing strategy for letters.

It should be noted that there was no longer a significant main effect of complexity on reaction time in the letter or shape task in Experiment 2. This suggests that the increase in WM demand altered the strategy with which both groups performed the task. Mental imagery accuracy, however, was influenced by stimulus complexity particularly for the shape condition in which accuracy was greater for simple than for complex stimuli.

As expected, individuals with schizophrenia showed WM deficits compared with controls on the spatial working memory task. There was a significant positive correlation between the shape imagery reaction time and spatial WM reaction time in controls but not in patients. This finding is consistent with earlier reports of an association between mental imagery and WM performance in healthy individuals (Baddeley & Andrade, 2000), but differed from the results of Experiment 1, in which we did not observe an association between imagery and WM. This discrepancy between Experiments 1 and 2 may be due to the poorer temporal resolution of the touch screen used in Experiment 1, resulting in reduced precision and reliability of RT measurements. In patients more severe negative symptoms were related to

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

reduced imagery accuracy in both the letter and shape tasks, however, there were no correlations with positive symptoms.

General Discussion

In two experiments, we examined visuospatial mental imagery and spatial WM performance in individuals with schizophrenia and matched healthy controls. We found evidence for imagery enhancement in schizophrenia patients in Experiment 1; in Experiment 2 the introduction of an increased WM maintenance demand abolished this enhancement effect.

Taken together these results suggest that individuals with schizophrenia are able reliably to generate and control internal representations in order to form mental images when they can access LTM and if there are almost no WM maintenance demands. The introduction of increased WM maintenance demand within the imagery task in Experiment 2 resulted in a loss of the imagery advantage for individuals with schizophrenia. This finding suggests that imagery can be generated and inspected without any difficulty by schizophrenia patients but that these mental representations are not maintained in WM. This problem with maintenance may not be a simple matter of faster, passive decay. There is evidence to indicate that mental representations do not decay more quickly in schizophrenia (Gold et al., 2010; Hanh et al., 2011), so it is puzzling why WM maintenance is problematic. To address this question, it is necessary to differentiate passive decay from active maintenance. It is assumed that manipulation of internal representation is more difficult than maintenance because maintenance is thought to be purely passive. However, maintenance in WM is not actually passive. In nonhuman primates, the maintenance of mental representations is implemented by increased firing rates of single cell units in multiple cortical regions including Brodmann's Area 46 (Goldman-Rakic, 1999). Similar observations have been reported in functional neuroimaging studies of WM maintenance using the spatial delayed-response paradigm, which show a robust increase in BOLD signals during the delay period in the dorsolateral prefrontal cortex (Driesen et al., 2008; Lee et al., 2008; Leung, Gore, & Goldman-Rakic, 2002). Keeping the internal representations alive in WM requires paying attention to the mental images and there is a metabolic cost to this process. In Experiment 2, when subjects were required to generate and inspect images as well as maintain them, the added cognitive demand of the maintenance process may have attenuated the facilitating effect of the superior imagery generation ability in schizophrenia patients.

One major question stemming from these results is whether enhanced generation and inspection of mental images from LTM and impaired maintenance of mental representations in WM can be explained within a unified framework. Although there is an extensive literature documenting impairments in both WM (Lee & Park, 2005) and LTM (Aleman, Hijman, de Haan, & Kahn, 1999) in schizophrenia, there has been relatively little research on the interactions between these two systems in patients (for an exception, see Barch, Csernansky, Conturo, & Snyder, 2002). A consideration in conceptualising the current findings is the ease to which representations in LTM can be brought into the focus of WM. For example, more readily accessible information from LTM into WM in schizophrenia could account for enhanced mental imagery of highly familiar images, categories, etc. One could also posit that if information transfer from LTM to WM was not effectively

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

inhibited, intrusion of task-irrelevant information from LTM might interfere with the maintenance of task-relevant information in WM. Although, to our knowledge, direct experimental investigation of this claim is lacking, the notion of ineffective inhibition of information from LTM on sensory processing is present in several related accounts of hallucinations in schizophrenia (e.g., George & Neufield, 1985; Helmsley, 1987; Rund, 1986). Further, results from Kopp (2007) suggest greater similarity-related intrusion of information from LTM into the contents of working memory in psychometrically identified schizotypal individuals. Thus, the simultaneous enhanced mental imagery and impaired WM in SZ observed in this study might both have a basis in the transfer of information from LTM to WM, which facilitates image generation, but hinders the controlled maintenance of a specific representation.

There are a number of limitations to be considered when interpreting these results. First, our sample sizes were relatively modest, but the effect size of the group difference in the imagery condition in Experiment 1 was robust despite the small sample size. However, given the small sample sizes, it would be important to replicate and confirm these findings independently in the future. Second, all our patients were chronic, medicated outpatients. Therefore, it is unknown whether the observed enhancement in mental imagery manipulation would also be present in acutely psychotic patients, and we cannot rule out the potential effects of antipsychotic medication. However, it is very unlikely that antipsychotic drugs were responsible for the observed enhanced imagery manipulation (i.e., *faster* RTs) in schizophrenia. Dopamine antagonists tend to increase motor RT in the rodent (Hauber, 1996), but the effects of antipsychotic drugs on RT in individuals with schizophrenia remain unclear (Kern et al., 1998). Moreover, medication-free patients with schizophrenia show generalised slowing in tasks that require manual responses (Gale & Holzman, 2000; Shakow & Huston, 1936). Therefore, psychomotor slowing in schizophrenia seems to be mostly independent of the effects of antipsychotic drugs, which makes our finding of faster or intact RT in schizophrenic patients even more striking.

In the present study, we found evidence that patients are able to generate and control mental images, but found no relationship between this ability and the experience of hallucinations in the disorder. However, it remains to be determined whether auditory imagery may be of special interest in this regard as a large proportion of our patient group reported auditory rather than visual hallucinations.

There is increasing recognition that cognitive deficits are important predictors of functional outcome in schizophrenia (Green et al., 2000). However, Brendan Maher (1996) has argued persuasively for the implementation of tasks in which the "putative psychopathology should lead to superior performance" to rule out the shadow of the generalised cognitive deficit in schizophrenia. Indeed, there are many observations of encapsulated, enhanced, or spared cognitive abilities in the disorder. These include better mental rotation performance (Thakkar & Park, 2012), increased indirect priming (Spitzer, Braun, Maier, Hermle, & Maher, 1993), superior size-weight illusion (Williams, Ramachandran, Hubbard, Braff, & Light, 2010) and intact divergent thinking (Folley & Park, 2005). We propose that to fully understand the behavioural endophenotype of schizophrenia, we must specify both the impaired and enhanced abilities. Our finding of consistently impaired maintenance but enhanced manipulation of internal representations provides a more nuanced picture of the working memory deficit in schizophrenia and highlights the importance of specifying neurocognitive targets for remediation.

Acknowledgements

We would like to thank Heath Nichols, Amanda Cumming, Randy Minas, and Jejoong Kim for their help.

Funding

This work was supported in part by NIH [MH073028] to SP and NIH [HD015052] to the Vanderbilt Kennedy Center.

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

References

Aleman, A., Bocker, K. B., Hijman, R., de Haan, E. H., & Kahn, R. S. (2003). Cognitive basis of hallucinations in schizophrenia: Role of top-down information processing. *Schizophrenia Research*, *64*, 175–185. doi:10.1016/S0920-9964(03)00060-4

Aleman, A., de Haan, E. H. F., & Kahn, R. S. (2005). Object versus spatial mental imagery in patients with schizophrenia. *Journal of Psychiatric Neuroscience*, *30*, 53–56.

Aleman, A., Hijman, R., de Haan, E. H. F., & Kahn, R. S. (1999). Memory impairment in schizophrenia: A meta-analysis. *American Journal of Psychiatry*, *156*, 1358–1366.

Andreasen, N. C. (1983). *The scale for the assessment of negative symptoms (SANS)*. Iowa City: University of Iowa.

Andreasen, N. C. (1984). *The scale for the assessment of positive symptoms (SAPS)*. Iowa City: University of Iowa.

Baddeley, A. D. (1992). Working memory. *Science*, *255*, 556–559. doi:10.1126/science.1736359

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience*, *4*, 829–839. doi:10.1038/nrn1201

Baddeley, A. D., & Andrade, J. (2000). Working memory and the vividness of imagery. *Journal of Experimental Psychology*, *129*, 126–145. doi:10.1037/0096-3445.129.1.126

Barch, D. M., & Csernansky, J. G. (2007). Abnormal parietal cortex activation during working memory in schizophrenia: Verbal phonological coding disturbances versus domain general executive dysfunction. *American Journal of Psychiatry*, *164*, 1090–1098. doi:10.1176/appi.ajp.164.7.1090

Barch, D. M., Csernansky, J. G., Conturo, T., & Snyder, A. Z. (2002). Working and long-term memory deficits in schizophrenia: Is there a common prefrontal mechanism?. *Journal of Abnormal Psychology*, *111*, 478–494. doi:10.1037/0021-843X.111.3.478

Bentall, R. P. (1990). The illusion of reality: A review and integration of psycholigical research on hallucinations. *Psychological Bulletin*, *17*, 82–95. doi:10.1037/0033-2909.107.1.82

Bocker, K. B., Hijman, R., Kahn, R. S., & De Haan, E. H. (2000). Perception, mental imagery and reality discrimination in hallucinating and non-hallcuinating schizophrenia patients. *British Journal of Clinical Psychology*, *39*, 397–406. doi:10.1348/014466500163392

Borst, G., Ganis, G., Thompson, W. L., & Kosslyn, S. M. (2012). Representations in mental imagery and working memory: Evidence from different types of visual masks. *Memory and Cognition*, *40*, 204–217. doi:10.3758/s13421-011-0143-7

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436. doi:10.1163/156856897X00357

Briggs, S. D., Raz, N., & Marks, W. (1999). Age-related deficits in generation and manipulation of mental images: The role of sensorimotor speed and working memory. *Psychology and Aging*, *14*, 427–435. doi:10.1037/0882-7974.14.3.427

Bruyer, R., & Scailquin, J. C. (2000). Effects of aging on the generation of mental images. *Experimental Aging Research*, *26*, 337–351. doi:10.1080/036107300750015732

Cannon, T. D., Glahn, D. C., Kim, J., van Erp, T. G., Karlsgodt, K., Cohen, M. S., & Shirinyan, D. (2005). Dorsolateral prefrontal cortex activity during maintenance and manipulation of information in working memory in patients with schizophrenia. *Archives of General Psychiatry*, *62*, 1071–1080. doi:10.1001/archpsyc.62.10.1071

David, A. S., & Cutting, J. C. (1992). Visual imagery and visual semantics in the cerebral hemispheres in schizophrenia. *Schizophrenia Research*, *8*, 263–271. doi:10.1016/0920-9964(93)90025-E

de Vignemont, F., Zalla, T., Posada, A., Louvegnez, A., Koenig, O., Georgieff, N., & Franck, N. (2006). Mental rotation in schizophrenia. *Consciousness and Cognition*, *15*, 295–309. doi:10.1016/j.concog.2005.08.001

Driesen, N. R., Leung, H. C., Calhoun, V. D., Constable, R. T., Gueorguieva, R., Hoffman, R., & Krystal, J. H. (2008). Impairment of working memory maintenance and response in schizophrenia: Functional magnetic resonance imaging evidence. *Biological Psychiatry*, *64*, 1026–1034. doi:10.1016/j.biopsych.2008.07.029

First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. W. (1997). *Structured clinical interview for DSM-IV Axis I disorders (SCID-1)*. Arlington, VA: APPI.

Folley, B. S., & Park, S. (2005). Verbal creativity and schizotypal personality in relation to prefrontal hemispheric laterality: A behavioral and near-infrared optical imaging study. *Schizophrenia Research*, *80*(2–3), 271–282. doi:10.1016/j.schres.2005.06.016

Gale, H. J., & Holzman, P. S. (2000). A new look at reaction time in schizophrenia. *Schizophrenia Research*, *46*, 149–165. doi:10.1016/S0920-9964(00)00006-2

George, L., & Neufeld, R. W. J. 1985. Cognition and symptomatology in schizophrenia. *Schizophrenia Bulletin*, *11*, 264–285. doi:10.1093/schbul/11.2.264

Glahn, D. C., Therman, S., Mannien, M., Huttunen, M., Kaprio, J., Lonnqvist, J., & Cannon, T. D. (2003). Spatial working memory as an endophenotype for schizophrenia. *Biological Psychiatry*, *53*, 624–626. doi:10.1016/S0006-3223(02)01641-4

Gold, J. M., Hanh, B., Zhang, W., Robinson, B. M., Kappenman, E. S., Beck, V. M., & Luck, S. L. (2010). Reduced capacity but spared precision and maintenance of working memory representations in schizophrenia. *Archives of General Psychiatry*, *67*, 570–577. doi:10.1001/archgenpsychiatry.2010.65

Goldman-Rakic, P. S. (1999). The physiological approach: Functional architecture of working memory and disordered cognition in schizophrenia. *Biological Psychiatry*, *46*, 650–661. doi:10.1016/S0006-3223(99)00130-4

Green, M. F., Kern, R. S., Braff, D. L., & Mintz, J. (2000). Neurocognitive deficits and functional outcome in schizophrenia: Are we measuring the right stuff?. *Schizophrenia Bulletin*, *26*, 119–136. doi:10.1093/oxfordjournals.schbul.a033430

Haenschel, C., Bittner, R. A., Waltz, J., Haertling, F., Wibral, M., Singer, W., & Rodriguez, E. (2009). Neural mechanisms of working memory deficits in early onset schizophrenia—contribution of disturbed oscillatory activity. *Journal of Neuroscience*, *29*, 9481–9489. doi:10.1523/JNEUROSCI.1428-09.2009

Hanh, B., Kappenman, E. S., Robinson, B. M., Fuller, R. L., Luck, S. J., & Gold, J. M. (2011). Iconic decay in schizophrenia. *Schizophrenia Bulletin*, *37*, 950–957. doi:10.1093/schbul/sbp164

Hauber, W. (1996). Impairments of movement initiation and execution induced by a blockade of dopamine D1 or D2 receptors are reversed by a blockade of N-methyl-D-aspartate receptors. *Neuroscience*, *73*, 121–130. doi:10.1016/0306-4522(96)00036-X

Hemsley, D. R. (1987). Hallucinations: Unintended or unexpected. *Behavioral and Brain Sciences*, *10*, 532–533. doi:10.1017/S0140525X00023943

Keogh, R., & Pearson, J. (2011). Mental imagery and visual working memory. *PLoS ONE*, *6*, e29221. doi:10.1371/journal.pone.0029221

Kern, R. S., Green, M. F., Marshall, B. D., Jr., Wirshing, W. C., Wirshing, D., McGurk, S., & Mintz, J. (1998). Risperidone vs. haloperidol on reaction time, manual dexterity, and motor learning in treatment-resistant schizophrenia patients. *Biological Psychiatry*, *44*, 726–732. doi:10.1016/S0006-3223(98)00088-2

Kopp, B. (2007). Mnemonic intrusions into working memory in psychometrically identified schizotypal individuals. *Journal of Behavior Therapy and Experimental Psychiatry*, *38*, 56–74. doi:10.1016/j.jbtep.2006.05.001

Kosslyn, S. M. (1980). *Image and mind*. Cambridge, MA: MIT Press.

Kosslyn, S. M. (1988). Aspects of a cognitive neuroscience of mental imagery. *Science*, *240*, 1621–1626. doi:10.1126/science.3289115

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Kosslyn, S. M., Cave, C. B., Provost, D. A., & von Gierke, S. M. (1988). Sequential processing in image generation. *Cognitive Psychology*, *20*, 319–343. doi:10.1016/0010-0285(88)90002-3

Lee, J., Folley, B. S., Gore, J. C., & Park, S. (2008). Origins of spatial working memory deficit in schizophrenia: An event-related fMRI and near-infrared spectroscopy study. *PLoS ONE*, *3*, e1760. doi:10.1371/journal.pone.0001760

Lee, J., & Park, S. (2005). Working memory impairments in schizophrenia: A meta-analysis. *Journal of Abnormal Psychology*, *114*, 599–611. doi:10.1037/0021-843X.114.4.599

Leung, H.-C., Gore, J. C., & Goldman-Rakic, P. S. (2002). Sustained mnemonic response in the human middle frontal gyrus during online storage of spatial memoranda. *Journal of Cognitive Neuroscience*, *14*, 659–671. doi:10.1162/08989290260045882

Logie, R. H. (1995). *Visuospatial working memory*. Hove: Lawrence Erlbaum Associates.

Maher, B. M. (1996). Cognitive psychopathology in schizophrenia. In D. L. Mattysse, J. Levy, J. Kagan, & F. Benes (Eds.), *Psychopathology: The evolving science of mental disorder* (pp. 433–451). Cambridge: Cambridge University Press.

Marks, D. F. (1973). Visual imagery differences in the recall of pictures. *British Journal of Psychology*, *1*, 17–24. doi:10.1111/j.2044-8295.1973.tb01322.x

Mintz, S., & Alpert, M. (1972). Imagery vividness, reality testing, and schizophrenia hallucinations. *Journal of Abnormal Psychology*, *79*, 310–316. doi:10.1037/h0033209

Myles-Worsley, M., & Park, S. (2002). Spatial working memory deficits in schizophrenia patients and their first degree relatives from Palau, Micronesia. *American Journal of Medical Genetics*, *114*, 609–615.

Nelson, H. E. (1982). *The National Adult Reading Test*. Windsor: NFER-Nelson.

Oertel, V., Rotarska-Jagiela, A., van de Ven, V., Haenschel, C., Grube, M., Stangier, U., & Linden, D. E. J. (2009). Mental imagery vividness as a trait marker across the schizophrenia specturm. *Psychiatry Research*, *167*, 1–11. doi:10.1016/j.psychres.2007.12.008

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97–113. doi:10.1016/0028-3932(71)90067-4

Overall, J. E., & Gorham, D. R. (1962). The Brief Psychiatric Rating Scale. *Psychological Reports*, *10*, 799–812. doi:10.2466/pr0.1962.10.3.799

Park, S., Holzman, P. S., & Goldman-Rakic, P. S. (1995). Spatial working memory deficits in the relatives of schizophrenic patients. *Archives of General Psychiatry*, *52*, 821–828. doi:10.1001/archpsyc.1995.03950220031007

Park, S., Puschel, J., Sauter, B. H., Rentsch, M., & Hell, D. (1999). Spatial working memory deficits and clinical symptoms in schizophrenia: A 4-month follow-up study. *Biological Psychiatry*, *46*, 392–400. doi:10.1016/S0006-3223(98)00370-9

Reilly, J. L., Harris, M. S., Keshavan, M. S., & Sweeney, J. A. (2006). Adverse effects of risperidone on spatial working memory in first-episode schizophrenia. *Archives of General Psychiatry*, *63*, 1189–1197. doi:10.1001/archpsyc.63.11.1189

Rund, B. R. (1986). Verbal hallucinations and information processing. *Behavioural and Brain Sciences*, *9*, 531–532. doi:10.1017/S0140525X00046975

Sack, A. T., van de Ven, V. G., Etschenberg, S., Schatz, D., & Linden, D. E. (2005). Enhanced vividness of mental imagery as a trait marker of schizophrenia?. *Schizophrenia Bulletin*, *31*, 97–104. doi:10.1093/schbul/sbi011

Shakow, D., & Huston, P. (1936). Studies of motor function in schizophrenia. I. Speed of tapping. *Journal of General Psychology*, *15*, 63–103. doi:10.1080/00221309.1936.9917905

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, *171*, 701–703. doi:10.1126/science.171.3972.701

Slotnick, S. D., Thompson, W. L., & Kosslyn, S. M. (2011). Visual memory and visual mental imagery recruit common control and sensory regions of the brain. *Cognitive Neuroscience*, *3*, 14–20. doi:10.1080/17588928.2011.578210

Spitzer, M., Braun, U., Maier, S., Hermle, L., & Maher, B. A. (1993). Indirect semantic priming in schizophrenia patients. *Schizophrenia Research*, *11*, 71–80. doi:10.1016/0920-9964(93)90040-P

Thakkar, K. N., & Park, S. (2012). Impaired passive maintenance and spared manipulation of internal representations in patients with schizophrenia. *Schizophrenia Bulletin*, *38*, 787–795. doi:10.1093/schbul/sbq159

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI) manual*. San Antonio, TX: Psychological Corporation.

Williams, L. E., Ramachandran, V. S., Hubbard, E. M., Braff, D. L., & Light, G. A. (2010). Superior size-weight illusion performance in patients with schizophrenia: Evidence for deficits in forward models. *Schizophrenia Research*, *121*, 101–106. doi:10.1016/j.schres.2009.10.021

Woods, S. W. (2003). Chlorpromazine equivalent doses for the newer atypical antipsychotics. *Journal of Clinical Psychiatry*, *64*, 663–667. doi:10.4088/JCP.v64n0607

Zarrinpar, A., Deldin, P., & Kosslyn, S. M. (2006). Effects of depression on sensory/motor vs central processing in visual mental imagery. *Cognition and Emotion*, *20*, 737–758. doi:10.1080/02699930500405600

Downloaded by [VUL Vanderbilt University] at 13:56 03 January 2014