Available online at www.sciencedirect.com

SCIENCE DIRECT®

Schizophrenia Research 80 (2005) 271–282

SCHIZOPHRENIA RESEARCH

www.elsevier.com/locate/schres

Verbal creativity and schizotypal personality in relation to prefrontal hemispheric laterality: A behavioral and near-infrared optical imaging study

Bradley S. Folley *, Sohee Park

Department of Psychology, Wilson Hall, Vanderbilt University 111, 21st Ave S, Nashville TN 37240, USA

Received 25 April 2005; received in revised form 2 June 2005; accepted 3 June 2005
Available online 24 August 2005

Abstract

Although anecdotal and correlational results have suggested a reliable relationship between creativity and psychosis, few studies have examined this relationship using empirical methods. In addition, little is known about the neural substrates of creative thinking. We investigated the creative thinking process in relation to schizotypal personality, schizophrenia and prefrontal hemispheric laterality using behavioral and near-infrared optical spectroscopy (NIRS) methods. Schizophrenic, psychometrically ascertained schizotypal, and healthy control subjects (all right-handed) participated in a novel "alternate uses" task designed to assess divergent thinking (DT) ability. The DT task required subjects to generate "uses" for conventional and ambiguous objects. Prefrontal activity was measured using NIRS while subjects were engaged in DT vs. a cognitive control task in a subset of the subjects. Behavioral data indicated that schizotypes had enhanced DT ability compared with schizophrenic and control subjects, who showed similar performance overall. NIRS data showed that DT was associated with bilateral prefrontal cortex (PFC) activation, but the right PFC particularly contributed to the enhanced creative thinking in psychometric schizotypes compared with the other two groups. Thus, creative thinking seems to robustly recruit bilateral PFC, but it is the right PFC that is preferentially activated in schizotypes in relation to their enhanced DT.

Keywords: Schizophrenia; Schizotypal personality; Schizotypy; Creativity; Divergent thinking; Hemispheric laterality; Near-infrared optical imaging; Functional neuroimaging; Prefrontal cortex

1. Introduction

Archival and biographic data from individuals with psychotic illnesses and from their relatives have supported the association between creativity and mental illness; however, few studies have used hypothesis-

* Corresponding author. Tel.: +1 615 322 3435; fax: +1 615 343 8449.
E-mail address: brad.folley@vanderbilt.edu (B.S. Folley).

0920-9964/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.schres.2005.06.016

driven and empirical methods to examine the link between creativity and psychosis.

There is overwhelming support for a positive relationship between creativity and schizotypy (cf. Eysenck and Furnham, 1993; Gianotti et al., 2001; Kline and Cooper, 1986; Merten and Fischer, 1999; O'Reilly et al., 2001; Poreh et al., 1994; Rawlings and Toogood, 1997; Rushton, 1990; Rust et al., 1989; Weinstein and Graves, 2001, 2002; Woody and Claridge, 1977; Zanes et al., 1998) but currently, there is little support for enhanced creative ability in schizophrenics (Andreasen and Powers, 1975; Cropley and Sikand, 1973; Keefe and Magaro, 1980; Shimkunas and Murray, 1974). Yet, several studies using retrospective analyses of birth records, found support for increased creativity in the relatives of schizophrenic individuals, rather than in the probands themselves (Karlsson, 1970, 1984). These results suggest that enhanced creativity may be masked by the psychotic illness in the probands but can be detected in those individuals who share a latent liability for psychosis. Examining a clearly defined aspect of creativity in relation to brain laterality in schizotypal individuals or those at high risk for schizophrenia is warranted.

Two major established theories define the process and products of creative thinking. Guilford (1959) has emphasized divergent thinking (DT) and the use of generative, flexible responses that redefine or elaborate upon an existing product or idea. Mednick (1962) built upon this definition, showing that creative thinking emphasizes generating novel associations. DT has emerged as a valid core element in the creative thinking process (Bartlett and Davis, 1974; Torrance, 1988).

The spread of activation through semantic networks is central to verbal DT models. When indirectly related associations are activated, creative solutions are thought to be enhanced (Mohr et al., 2001; Pizzagalli et al., 2001). Schizophrenic patients (Spitzer et al., 1993; Weisbrod et al., 1998) and schizotypes (Gianotti et al., 2001; Mohr et al., 2001; Pizzagalli et al., 2001) show increased indirect semantic priming, suggesting that semantic organization may be altered and accessing indirect connections may be easier for psychosis-prone individuals. It is also possible that greater spreading activation could increase across hemispheres in individuals who have decreased cerebral lateralization. The right frontal lobe is involved in generating unusual or distant verbal associations while the left frontal lobe is involved in generating "usual" associations (Kiefer et al., 1998; Seger et al., 2000) Enhanced creativity and schizotypy may be associated with increased *inter*hemispheric transfer (Miran and Miran, 1984), thereby making more efficient use of bilateral networks to generate associations.

Increased hemispheric interactions and reduced laterality may be central to both schizophrenia and creativity. Divergent and creative thinking may be characterized by increased cooperation of the two hemispheres (Atchley et al., 1999; Bekhtereva et al., 2000; Carlsson et al., 2000), and reduced hemispheric dominance has been linked to creativity (Claridge and Broks, 1984). Schizophrenia is associated with reduced functional and structural laterality. There is robust support for mixed handedness in schizophrenia (Cannon et al., 1995; Crow et al., 1996; DeLisi et al., 2002) and in schizotypes (Chapman and Chapman, 1987; Claridge et al., 1998; Kim et al., 1992; Richardson, 1994) rather than pure left-handedness (Shaw et al., 2001). Mixed handedness is associated with decreased cerebral lateralization, schizotypy, and enhanced creativity (Claridge and Broks, 1984). However, several neuroimaging and lesion studies also report specific RH correlates of creative thinking (Bowden and Beeman, 2003; Jung-Beeman et al., 2004; Martindale et al., 1984; Miller and Tippett, 1996; Razumnikova, 2004), although such unilateral functional preference may also be an outcome of *intra*hemispheric cooperation (Petsche, 1996; Razoumnikova, 2000). However, a direct comparison of these studies is problematic because definitions of "creativity" vary wildly.

In the present study we examined creative performance in normal controls, schizophrenics, and psychometrically ascertained schizotypes using a novel DT task in order to: (1) test the association between enhanced creativity and schizotypy; and (2) elucidate the neural correlates of DT. We examined hemispheric prefrontal activation during creative thinking using near infrared spectroscopy (NIRS) in a subset of subjects from the behavioral experiment. We hypothesized that DT would be associated with greater bilateral PFC activity and that the schizotypes would show greater PFC activity during DT than other groups.

2. Method

2.1. Subjects

Demographic information is presented in Table 1. 17 outpatient schizophrenic (SZ) subjects who met the DSM-IV criteria were recruited from a local clinic. 17 healthy control (CO) and 17 schizotypal (SCT) subjects were recruited from the community. Exclusion criteria included substance abuse, neurological disorders, and history of head trauma. All patients were taking atypical antipsychotic drugs and were clinically stable. There were no significant group differences in education, handedness, or intelligence.

A randomly selected subset of the subjects participated in the NIRS part of the study. 10 SZ, 10 SCT and 10 CO participated. There were no significant group differences in education, handedness, fluency, or IQ for this subset; but SCT were younger than SZ or CO.

The study was approved by the Vanderbilt Institutional Review Board, and informed consent was obtained from all participants, who were compensated.

Table 1
Demographic and clinical characteristics of the sample

Behavioral task participants	Normal control $N=17$	Schizotypal $N=17$	Schizophrenic $N=17$
% female	47%	47%	29%
Age	35.2 (3.1)	22.8 (1.8)	39.5 (2.6)
Years of education	12.9 $(0.3)_a$	13.9 $(0.3)_a$	13.0 $(0.5)_a$
Edinburgh	60.3 $(15.2)_a$	45.9 $(13.3)_a$	54.7 $(13.4)_a$
SPQ	20.9 (1.8)	44.7 (2.1)	–
BPRS	–	–	25.0 (3.9)
SANS	–	–	28.5 (3.9)
SAPS	–	–	27.3 (5.7)
WASI	101.6 $(3.4)_a$	111.1 $(3.5)_a$	100.4 $(3.2)_a$
Letter fluency	41.5 $(2.6)_a$	42.5 $(3.0)_a$	34.7 $(2.8)_a$
Category fluency	36.8 (1.7)	40.0 (1.5)	31.2 (1.2)
Design fluency	8.4 $(0.8)_a$	10.8 $(0.9)_a$	8.6 $(0.7)_a$
NIRS participants (subset of the above)	**Normal control $N=10$**	**Schizotypal $N=10$**	**Schizophrenic $N=10$**
% female	40%	50%	30%
Age	36.4 $(3.1)_a$	23.3 (1.6)	36.7 $(2.9)_a$
Years of education	13.2 $(0.4)_a$	13.8 $(0.4)_a$	13.4 $(0.3)_a$
Edinburgh	65.0 $(22.2)_a$	66.7 $(7.4)_a$	65.9 $(8.3)_a$
SPQ	19.3 (3.5)	41.5 (1.1)	–
BPRS	–	–	13.2 (3.0)
SANS	–	–	12.9 (3.0)
SAPS	–	–	12.4 (4.3)
WASI	98.0 $(5.2)_a$	112.3 $(5.3)_a$	99.8 $(6.0)_a$
Letter fluency	39.9 $(4.0)_a$	45.0 $(3.1)_a$	37.6 $(3.1)_a$
Category fluency	40.2 $(2.3)_a$	42.6 $(1.9)_a$	32.2 (1.9)
Design fluency	6.9 $(1.0)_a$	9.7 $(1.5)_a$	9.5 $(0.9)_a$

Values with the same subscript are statistically similar at $p > .05$ using the Sidak test within each variable. Values shown are Mean (S.E).

2.2. Design and material

Clinical symptoms and schizotypal personality questionnaires: For SZs, clinical symptoms were assessed with the Brief Psychiatric Rating Scale (BPRS; (Lukoff et al., 1986) and the Scales for the Assessment of Positive (SAPS) and Negative (SANS) Symptoms (Andreasen, 1982; Andreasen and Olsen, 1982). All normal subjects filled out the Schizotypal Personality Questionnaire (SPQ; (Raine, 1991), a self-report measure with 74 true–false items.

IQ, handedness and neuropsychological measures: General intellectual functioning was assessed using the Wechsler Abbreviated Scales of Intelligence (Psychological Corporation, 1999). The Modified Edinburgh Handedness Inventory (Schachter et al., 1987) was used to assess handedness. Fluency was measured using verbal (FAS; (Spreen and Strauss, 1998), category (animals and boys' names; (Spreen and Strauss, 1998), and design (Five Point Test; (Regard et al., 1982) fluency tasks.

Creativity tasks: We used the Remote Associates Test (RAT) (Mednick, 1962) and developed a novel divergent thinking task based on earlier models of creativity (Guilford, 1959; Torrance, 1988; Wallach and Kogan, 1965). The RAT is a paper-and-pencil task. Thirty sets of three words are presented and subjects are required to find a word that links the three target words in the set. For example, given the word set of blue, cake and cottage, the correct answer would be 'cheese'. The RAT requires association generation and convergent thinking in order to link the remote associations.

The novel Divergent Thinking Task (*DTT*) required subjects to generate 'uses' for real objects. Each trial began with the presentation of the stimulus object or objects. Subjects then touched and explored the object(s) and described how they would use the object(s). There was no time limit. Subjects' responses were recorded verbatim by the experimenter. Subsequent trials began when subjects said that they had

finished generating 'uses'. There were two types of object conditions (see Fig. 1). For half of the trials, common, familiar objects were presented (conventional condition). For the other half, unfamiliar, novel objects were presented (ambiguous condition). There were 5 trials per condition. Each trial had different number of objects ranging from 1–5 items. For single object trials, subjects generated uses for that item. For trials that contained multiple objects, subjects were asked to generate uses for the objects alone and in combination. Thus the task demand was varied with increasing the "combinatory load" (i.e., generating uses for a combination of the objects).

NIRS was performed using a 24-channel spectrometer (Hitachi ETG-100 system) using two amplitude modulated (0.6 and 1.5 kHz) laser diodes (3 ± 0.15 mW) with wavelengths of 780(± 20) and 830(± 20) nm. Signals were acquired at 10 Hz from PFC and converted to chromophore concentrations (oxyhemoglobin (oxyHB), deoxyhemoglobin (deoxyHB), and total HB using the modified Beer–Lambert Law. Probes were placed on the forehead according to the International 10–20 system of EEG electrode placement (Fig. 3a) with RH probes covering areas Fp2, F4 and F8, and LH probes covering areas Fp1, F5 and F7.

A modified DTT using pictures of common household objects was used in a block design for the NIRS experiment. Modifying the behavioral task was necessary to avoid motion artifact produced during speaking. Therefore, the modified DTT required key presses during NIRS recording, but we recorded the ideas generated immediately after each run (see below).

In the modified DTT, a target object was presented above a central fixation point on a computer screen with an array of 8 other, numbered objects below the fixation point. Subjects were required to decide which objects in the array could be "used" with the target. They indicated their response by pressing number keys corresponding to the numbered objects. To control for the categorization and decision making components of the DTT, we included a control task. In the control task, a target object was presented on top of a computer screen with an array of 8 other, numbered objects below it. Subjects were required to decide which objects were similar in color to the target and indicate their choices by pressing the keys corresponding to the numbered objects. Identical objects were shown during the control and DT tasks. The key presses were recorded.

Each "run" contained 1 control and 1 DT trial (Fig. 2) and was conducted as follows. There was a 15-s baseline fixation at the beginning of each run. Next, an instruction screen was presented for 5 s that alerted subjects to get ready for the "color" task. Then, a stimulus screen containing objects was presented for 30 s during which subjects made their responses.

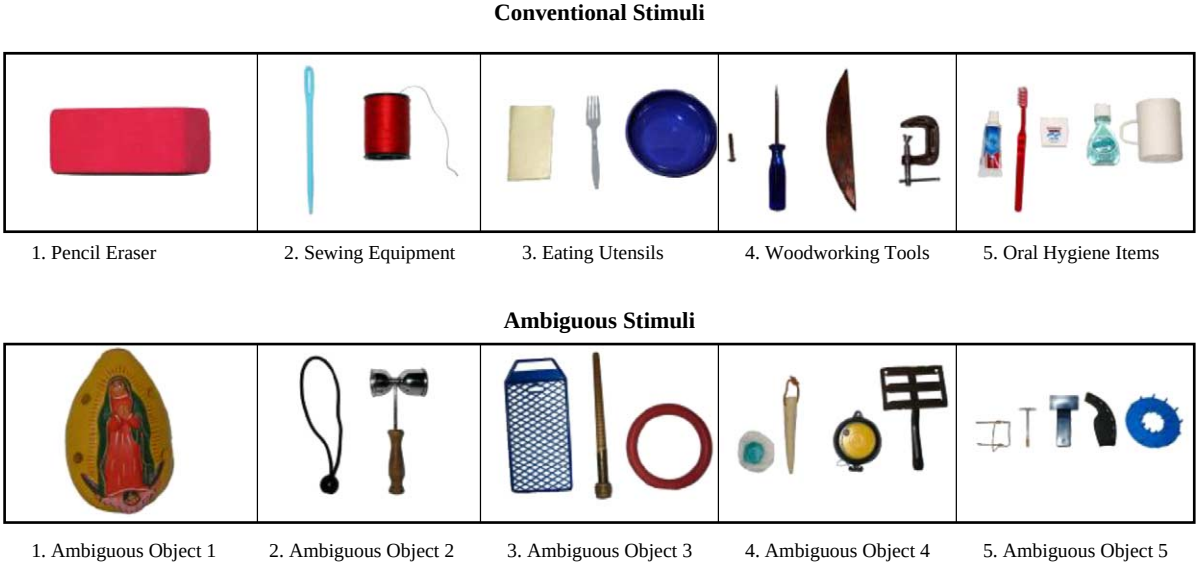

Fig. 1. Stimuli used in the novel divergent thinking task showing the conventional and ambiguous objects.

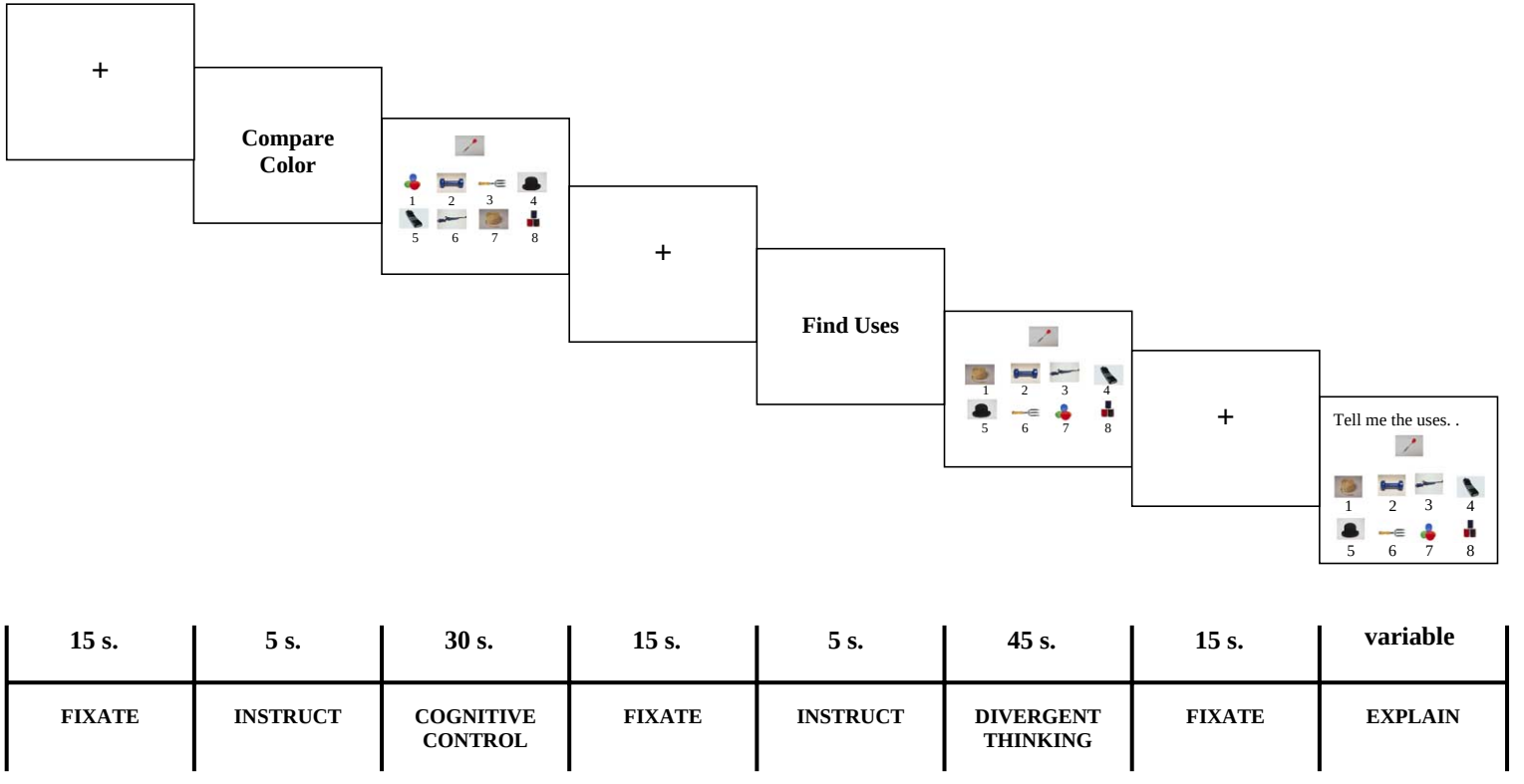

Fig. 2. Cognitive paradigm used for the modified divergent thinking task in the NIRS experiment showing the control (compare color) and the divergent thinking (find uses) tasks.

There was a 15-s fixation period followed by a 5-s instruction screen that alerted subjects to get ready for the "uses" task. Then the stimulus screen was presented for 45 s during which subjects made their responses. This was followed by another 15-s fixation period. This sequence of events constituted one run.

Immediately after each run, the DT stimulus screen was displayed again indefinitely and subjects were asked to verbalize their responses that they had made in the previous run. This was done to verify the ideas generated during the modified DTT. The verbal description was recorded by the experimenter. There were 6 runs per subject.

3. Results

RAT: For the number of correct responses on the RAT, there was a main effect of group ($F(2,48)=4.03$, $p<0.05$; $r=0.39$). Normal controls ($M=10.0$, SD=6.1) gave more correct responses than schizophrenics ($M=5.5$, SD=4.3) ($p<0.05$).

DTT: We recorded the number of singular and combinatory uses. For each trial, single object "use" responses were summed. Combinatory responses were calculated for each trial by summing the number of responses that included a use for at least two objects within the stimulus set. In addition, a total response time for each trial was calculated. Interrater reliability for scoring the DT task was high (IC=0.94).

Convergent and discriminant validity for our novel DTT were assessed by comparing it with correct responses and number of associations made for each word triad in the RAT. The number of associations produced on the RAT was correlated with the total number of uses, (rho=.48, $p<0.001$), conventional object uses (rho=.39, $p<0.01$), and ambiguous object uses (rho=.52, $p<0.001$) scores on the novel DT task, all being measures of divergent thinking. However, convergent thinking, assessed by number of correct responses on the RAT was *not* associated with total, conventional, or ambiguous alternate uses scores on the DTT (rho=.11 to .16, $p=ns$).

Singular Uses: A repeated measure ANOVA showed that there was a significant main effect of diagnostic group, ($F(2,48)=6.39$, $p<0.01$; $r=0.49$). SCT ($M=120.6$, SD=92.5) generated more uses than CO ($M=67.5$, SD=24.3) ($p<0.05$) and SZ ($M=55.2$, SD=22.9) ($p<.01$). The main effect for object type was significant ($F(1,48)=5.73$, $p<0.05$; $r=0.47$). All subjects gave more responses to ambiguous objects ($M=43.14$, SD=34.59) compared to conventional objects ($M=37.9$, SD=29.7). The interaction between diagnostic group and object type was not significant ($F(2,48),=.44$, $p=ns$).

Combinatory Uses: A repeated-measure ANOVA showed that there was a main effect of group ($F(2,48)=4.26$, $p<0.05$; $r=0.40$). SCT gave more combinatory responses ($M=24$, SD=22.13) compared to SZ ($M=12.0$, SD=10.2) ($p<0.05$), and CO ($M=10.8$, SD=6.6) ($p<0.05$). The main effect of object type was also significant ($F(1,48)=19.16$, $p<0.001$; $r=0.72$), indicating that subjects made more combinatory responses to conventional objects ($M=10.4$, SD=10.9) than ambiguous objects ($M=5.2$, SD=5.8). The interaction between group and object type was not significant ($F(2,48)=.69$, $p=ns$).

Schizotypy: Spearman's rho (one-tailed) was calculated for associations between DT and SPQ scores (Table 2) without correcting for multiple comparisons. Overall, higher SPQ scores were associated with greater creative use generation. The Disorganization factor (odd speech and behavior) was particularly associated with all creative fluency measures. SPQ variables were inversely associated with dextrality, especially for the Disorganization factor (rho=−0.51, $p<0.01$). Overall, total SPQ scores were also inversely associated with dextrality (rho=−0.34, $p<0.05$).

Handedness: There was an inverse relationship between DT and handedness (range=−0.14 to −0.27), although these correlations were not statistically significant. Because we recruited right-handed subjects for this study, this may be reflected by range restriction in handedness. Yet, the direction of the correlations for all variables is in the inverse

Table 2
Correlations between divergent thinking scores and SPQ total and factor scores

Stimulus type	SPQ total	SPQ positive	SPQ negative	SPQ disorganized	SPQ odd speech	SPQ odd behavior
Total singular uses	.44**	.31*	.24	.46**	.45**	.43**
Conventional objects	.35*	.25	.20	.35*	.35*	.30
Ambiguous objects	.44**	.35*	.19	.49**	.47**	.48**
Total combinatory uses	.40**	.24	.34*	.43**	.44**	.37*
Conventional combinatory	.37*	.18	.37*	.33**	.38*	.34
Ambiguous combinatory	.46**	.33*	.28	.51***	.52**	.44**

Correlation is Spearman's rho. $N=51$. All correlations are one-tailed. Significance: *=.05; **=.01; ***=.001.

direction, suggesting that decreased dextrality may be associated with greater DT.

Behavioral data from the modified DTT: We examined the number of uses generated and the response rate in the control and DT tasks using repeated measure ANOVAs. Although there was a time limit (30 s for control task and 45 s for DTT), subjects generally did not use the entire time allotted to generate responses.

For number of uses, there was a main effect for task type ($F(1,27)=10.7$, $p<0.01$; $r=0.70$). Subjects gave more responses for the DT task ($M=3.8$, SD=1.2) than the control task ($M=3.1$, SD=0.7). The main effect for group was not significant ($F(2,27)=1.19$, $p=ns$). The interaction between group and task type was significant ($F(2,27)=4.37$, $p<0.05$; $r=0.50$). CO reported more color similarities on the control task ($M=3.4$, SD=0.6) than SCT did ($M=2.8$, SD=0.8) ($p<0.05$), but on the DT task SCT generated more uses ($M=4.4$, SD=1.0) compared to SZ ($M=3.2$, SD=1.2) ($p<0.05$).

For response rate, there was a main effect of task type ($F(1,27)=52.6$, $p<0.001$; $r=0.92$). Subjects responded at a higher rate to the control task ($M=0.24$, SD=0.08) than the DTT ($M=0.15$, SD=0.04). Neither the main effect of group ($F(2,27)=0.77$, $p=ns$) nor the interaction between group and task type ($F(2,27)=0.42$, $p=ns$) were significant.

NIRS Analyses: Raw absorbance data were processed in *Matlab*™ including respiration and cardiac artifacts (0.01–0.5 Hz) removal, temporal downsampling (10–1 Hz.), normalization, conversion to chromophore measurements, and bilinear smoothing. *Brain Voyager QX*™ was used for linear drift correction and statistical analyses using the epochs measured for the control and DT tasks as the two main predictors which were convolved with a hemodynamic boxcar function (Boynton et al., 1996). The false discovery rate statistic q(FDR) protected contrasts from alpha inflation. Separate contrasts were performed for the within-subjects (DT vs. control task) and between-subjects analyses. Results are reported for clusters that passed a threshold criterion of 20+ voxels. Results from all chromophores are shown in Table 3.

Statistical maps for oxyHB data are shown in Fig. 3. Fig. 3b shows the significant ($p<0.01$) bilateral prefrontal increase in oxyHB associated with performance on the DT task compared to the control task (see Table 3 for statistical values). Total HB values also showed a significant bilateral increase. The bilateral increase in deoxyHB was unexpected.

Group differences (Table 3) were observed in contrasts performed on the oxyHB data, which indicate a significant increase in the right PFC (RPFC) for SCT during DT compared to CO ($p<0.01$) (Fig. 3c) and SZ ($p<0.01$) (Fig. 3d). No significant group differences were observed in oxyHB during DT between SZ and CO (Fig. 3e). In

Table 3
Hemispheric results from the NIRS study based on contrasts for each chromophore

Chromophore	Contrast	Group 1	LH increase		RH increase		Group 2	LH increase		RH increase	
			Peak t df(46242)	$p<$	Peak t df(46242)	$p<$		Peak t df(46242)	$p<$	Peak t df(46242)	$p<$
Oxyhemoglobin	Within	DT-Color	13.94	.00001	10.02	.00001					
	Between	Schizotype			4.45	.00001	Normal				
		Schizophrenic					Schizotype			6.14	.00001
		Normal					Schizophrenic				
Deoxyhemoglobin	Within	DT-color	7.24	.00001	4.31	.001					
	Between	Schizotype	3.64	.001			Normal	4.44	.00001	5.12	.00001
		Schizophrenic	4.79	.00001			Schizotype			4.94	.00001
		Normal	3.69	.001			Schizophrenic	3.72	.001	7.61	.00001
Total Hemoglobin	Within	DT-color	11.54	.00001	7.5	.00001					
	Between	Schizotype					Normal				
		Schizophrenic	4.41	.00001			Schizotype			5.75	.00001
		Normal	4.44	.00001	3.16	.01	Schizophrenic	3.67	.001		

All post hoc contrasts are corrected for multiple comparisons using the q(FDR) method. Only cluster sizes of 20+ voxels are reported.

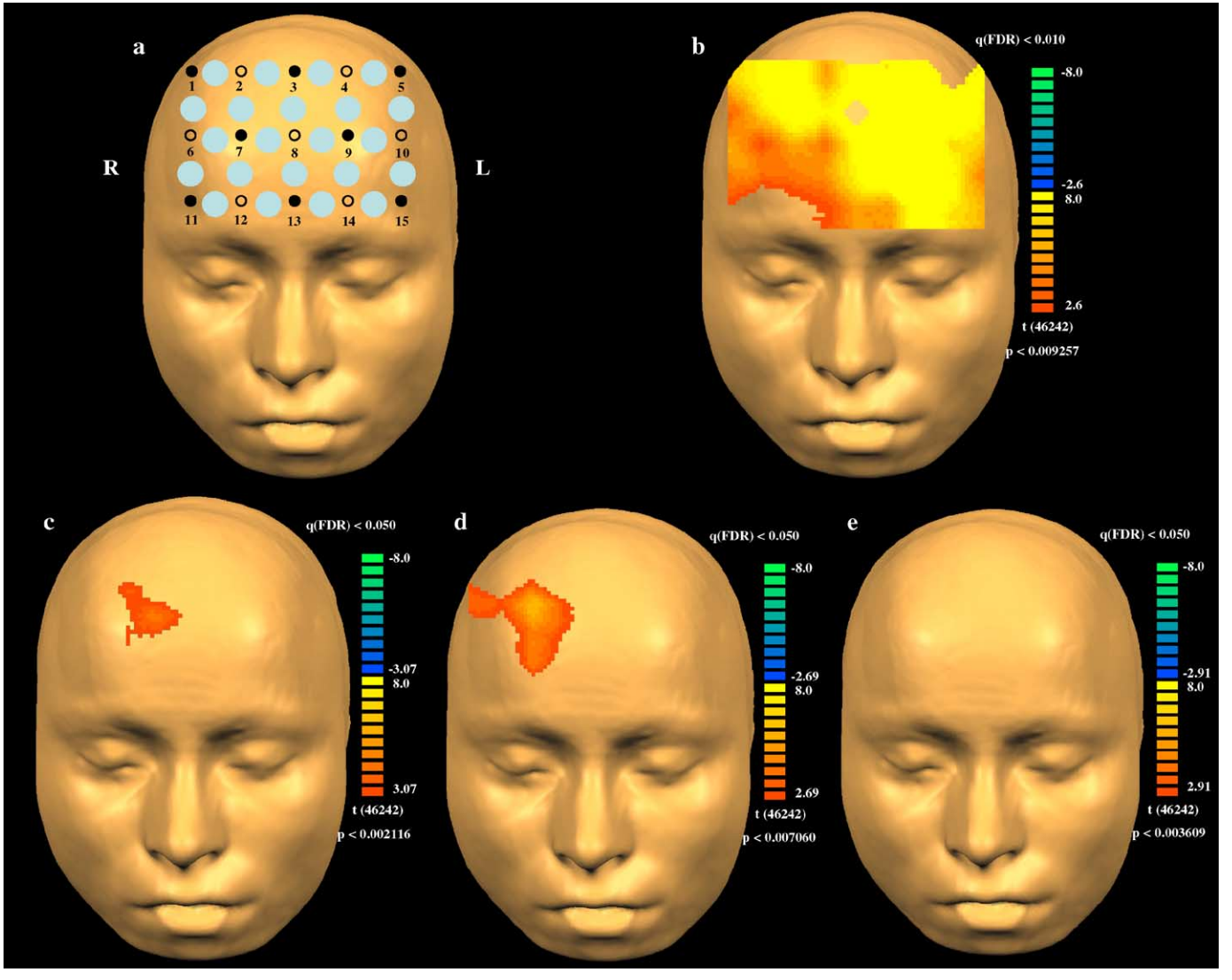

Fig. 3. NIRS results comparing the divergent thinking task to the cognitive control task. a) Location of the 22 channel placement with the 3 × 5 probe holder. Small circles represent emitters (closed) and detectors (open). Large circles represent measurement channels (22); b) Bilateral PFC oxyHB increase during the DT condition compared to the control task across subjects; c) RH increase in oxyHB only (schizotypes > normal controls); d) RH increase in oxyHB only (schizotypes > schizophrenics); e) No differences in oxyHB concentrations between normal controls and schizophrenics.

contrast, all groups showed increased deoxyHB in RPFC during DT, although CO also showed increased left PFC (LPFC) deoxyHB compared to SCT, and SZ showed increased LPFC deoxyHB compared to CO. SZ showed greater LPFC totalHB concentrations compared to other groups, while SCT and CO had greater RPFC totalHB levels compared to SZ.

4. Discussion

The major findings of this study were that: (1) schizotypy is associated with enhanced DT; (2) DT is particularly associated with disorganized schizotypal traits; (3) DT is associated with bilateral PFC activity; and (4) Schizotypes, who have enhanced creative thinking ability, recruit the right PFC preferentially compared to SZ and CO.

To our knowledge, this is the first study to compare the functional neuroanatomy of DT in SCT, SZ and CO. Our data support evidence for enhanced DT in schizotypes. This finding was not dependent on prior associative context among the stimuli used, as we found no interaction between group and stimulus type. The measure of *combinatory responses* may be a more robust determinant of creative thinking due to the increased associative load, and SCT also performed better on this measure compared to the other two groups.

DT ability was particularly associated with disorganized schizotypal traits. SPQ items that load onto this factor address slight abnormalities or oddities in speech and in non-verbal behavior, which are associated with social communication and transmission of ideas. This may imply a connection between creative production and the ability to express unconventional ideas, as Venables (1989) has argued that SCT may be able to direct their cognitive abnormalities toward creative, rather than dysfunctional, cognitive output.

NIRS oxyHB indicates that the differences in DT between SCT and SZ that were observed behaviorally were indicated by a greater reliance on RPFC activation for SCT. Although DT fluency from the modified DTT was not significantly different between SCT and CO, the chromophore data indicate that SCT also recruited the RPFC preferentially compared to CO during DT. Our hypothesis was partially supported. DT recruits the PFC bilaterally, but the differences between the SCT and the SZ and CO groups are due to preferential recruitment of the RH in DT for SCT rather than to increased bilateral processing. One caveat is that we relied on the oxyHB data to interpret our results rather than the deoxyHB and total HB data because 780 nm may have reduced sensitivity to deoxyHB (Sato et al., 2004).

Because the PFC is involved in processing of novelty, it is not surprising that we observed robust prefrontal activation during DT, which involves implementing novel associations. It is also clear that prefrontal activation during DT is bilateral. However, we also found that the RH may play an especially important role in DT in schizotypes. These results support previous neuroimaging studies that showed a significant RH advantage in creative thinking. Behavioral investigations have also suggested a RH processing bias for verbal creativity in schizotypes (Gianotti et al., 2001; Weinstein and Graves, 2001, 2002) which may stem from a RH advantage for processing unusual associations (Faust and Lavidor, 2003; Mohr et al., 2001; Pizzagalli et al., 2001; Rodel et al., 1992). Less LH reliance for verbal creativity may allow greater access to RH processes that are particularly salient in creative thinking (Brugger and Taylor, 2003). Our data are also consistent with other studies that found support for bilateral prefrontal activation during DT, however recruitment and activation of non-frontal regions in creative thinking paradigms has also been shown in verbal creativity tasks (Bechtereva et al., 2004). Future studies could examine how these cortical regions are coordinated during creative thinking.

There are some caveats. First, our study included only right-handed individuals. It would be helpful to investigate the full range of handedness in relation to DT and schizotypy, as these data suggest that schizotypy and DT are both related to decreased dextrality. Yet, although we examined right-handers only, we still observed significant differences in schizotypes and controls in the PFC activation patterns. Therefore, a future study with a full range of handedness is expected to show even clearer effect. Secondly, the DTT and modified DTT differed in the use of time limit. DT tasks provide maximal validity when they are not timed (Wallach, 1971), as was the procedure using the DTT where we obtained robust group differences. Although the NIRS modified DTT incorpo-

rated a time limit, SCT still performed significantly better than SZ and showed different PFC activation patterns compared with the other groups. Thus, despite the use of time limit in the NIRS experiment, we still observed significant group differences.

Both experiments showed similar creative thinking ability and PFC function in SZ and CO in contrast to most cognitive studies SZ that demonstrate deficits. Our SZ were chronic and medicated, but they were matched to CO for IQ and verbal fluency. What is remarkable is that this group of patients showed a range of cognitive deficits including memory (e.g., Park et al., 2004) and perception (Kim et al., in press), yet they perform as well as normal controls on DT.

The relationship between creativity and psychosis, although studied for centuries, has been difficult to specify. We have taken a step towards developing reliable tools for the empirical study of creativity and psychosis. This approach may help to bridge the gap between anecdotal evidence for the creativity/psychosis relationship and its underlying neural mechanisms.

Acknowledgments

We thank Crystal Gibson, Chris Cannistraci, Susan J. Hespos, John Gore, Gordon Claridge, Peter Brugger, Christine Mohr, and Lynn DeLisi. This work was supported in part by the Discovery Grant to S.P. and by an NIMH training grant (T32-MH18921) and NICHD Grant P30HD15052.

References

Andreasen, N.C., 1982. Negative symptoms in schizophrenia. Definition and reliability. Archives of General Psychiatry 39, 784–788.

Andreasen, N.C., Powers, P.S., 1975. Creativity and psychosis. An examination of conceptual style. Archives of General Psychiatry 32, 70–73.

Andreasen, N.C., Olsen, S., 1982. Negative v. positive schizophrenia. Definition and validation. Archives of General Psychiatry 39, 789–794.

Atchley, R.A., Keeney, M., Burgess, C., 1999. Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval and creativity. Brain and Cognition 40, 479–499.

Bartlett, M., Davis, G.A., 1974. Do the Wallach and Kogan tests predict real creative behavior? Perceptual and Motor Skills 39, 730.

Bechtereva, N.P., Korotkov, A.D., Pakhomov, S.V., Roudas, M.S., Starchenko, M.G., Medvedev, S.V., 2004. PET study of brain maintenance of verbal creative activity. International Journal of Psychophysiology 53, 11–20.

Bekhtereva, N.P., Starchenko, M.G., Klyucharev, V.A., Vorob'ev, V.A., Pakhomov, S.V., Medvedev, S.V., 2000. Study of the brain organization of creativity: II. Positron–emission tomography data. Human Physiology 26, 516–522.

Bowden, E.M., Beeman, M.J., 2003. Aha! Insight experience correlates with solution activation in the right hemisphere. Psychonomic Bulletin & Review 10, 730–737.

Boynton, G.M., Engel, S.A., Glover, G.H., Heeger, D.J., 1996. Linear systems analysis of functional magnetic resonance imaging in human v1. Journal of Neuroscience 16, 4207–4221.

Brugger, P., Taylor, K.I., 2003. ESP extrasensory perception or effect of subjective probability? Journal of Consciousness Studies 10, 221–246.

Cannon, M., Byrne, M., Cassidy, B., Larkin, C., Horgan, R., Sheppard, N.P., et al., 1995. Prevalence and correlates of mixed handedness in schizophrenia. Psychiatry Research 59, 119–125.

Carlsson, I., Wendt, P.E., Risberg, J., 2000. On the neurobiology of creativity. Differences in frontal activity between high and low creative subjects. Neuropsychologia 38, 873–885.

Chapman, J.P., Chapman, L.J., 1987. Handedness in hypothetically psychoses-prone subjects. Journal of Abnormal Psychology 96, 89–93.

Claridge, G., Broks, P., 1984. Schizotypy and hemisphere function I. Personality and Individual Differences 5, 633–648.

Claridge, G., Clark, K., Davis, C., Mason, O., 1998. Schizophrenia risk and handedness: a mixed picture. Laterality 3, 209–220.

Cropley, A.J., Sikand, J.S., 1973. Creativity and schizophrenia. Journal of Consulting and Clinical Psychology 40, 462–468.

Crow, T.J., Done, D.J., Sacker, S.A., 1996. Cerebral lateralization is delayed in children who later develop schizophrenia. Schizophrenia Research 22, 181–185.

DeLisi, L.E., Svetina, C., Razi, K., Shields, G., Wellman, N.A., Crow, T.J., 2002. Hand preference and hand skill in families with schizophrenia. Laterality 7, 321–332.

Eysenck, H.J., Furnham, A., 1993. Personality and the Barron–Welsh art scale. Psychological Reports 76, 837–838.

Faust, M., Lavidor, M., 2003. Semantically convergent and semantically divergent priming in the cerebral hemispheres: lexical decision and semantic judgment. Cognitive Brain Research 17, 585–597.

Gianotti, L.R., Mohr, C., Pizzagalli, D., Lehmann, D., Brugger, P., 2001. Associative processing and paranormal belief. Psychiatry and Clinical Neurosciences 55, 595–603.

Guilford, J.P., 1959. Traits of creativity. In: Anderson, H.H., University, M.S. (Eds.), Creativity and its Cultivation, Addresses Presented at the Interdisciplinary Symposia on Creativity, Michigan State University, East Lansing, Michigan, (1st ed.). Harper, New York, pp. 142–161.

Jung-Beeman, M., Bowden, E.M., Haberman, J., Frymiare, J.L., Arambel-Liu, S., Greenblatt, R., et al., 2004. Insight in the brain: neural activity when people solve verbal problems with insight. Public Library of Science Biology 2, 0500–0510.

Karlsson, J.L., 1970. Genetic association of giftedness and creativity with schizophrenia. Hereditas 66, 177–182.

Karlsson, J.L., 1984. Creative intelligence in relatives of mental patients. Hereditas 100, 83–86.

Keefe, J.A., Magaro, P.A., 1980. Creativity and schizophrenia: an equivalence of cognitive processing. Journal of Abnormal Psychology 89, 390–398.

Kiefer, M., Weisbrod, M., Kern, I., Maier, S., Spitzer, M., 1998. Right hemisphere activation during indirect semantic priming: evidence from event-related potentials. Brain and Language 64, 377–408.

Kim, D., Raine, A., Triphon, N., Green, M.F., 1992. Mixed handedness and features of schizotypal personality in a nonclinical sample. Journal of Nervous and Mental Disorders 180, 133–135.

Kim, J., Doop, M.L., Blake, R., Park, S., in press. Impaired visual recognition of biological motion in schizophrenia. Schizophrenia Research (Available online at Schizophrenia Research Website).

Kline, P., Cooper, C., 1986. Psychoticism and creativity. Journal of Genetic Psychology 147, 183–188.

Lukoff, D., Nuechterlein, K.H., Ventura, J., 1986. Manual for the expanded brief psychiatric rating scale. Schizophrenia Bulletin 12, 560–594.

Martindale, C., Hines, D., Mitchell, L., Covell, E., 1984. EEG alpha asymmetry and creativity. Personality and Individual Differences 5, 77–86.

Mednick, S.A., 1962. The associative basis of the creative process. Psychological Review 69, 220–232.

Merten, T., Fischer, I., 1999. Creativity, personality and word association responses: associative behaviour in forty supposedly creative persons. Personality and Individual Differences 27, 933–942.

Miller, L.A., Tippett, L.J., 1996. Effects of focal brain lesions on visual problem-solving. Neuropsychologia 34, 387–398.

Miran, M., Miran, E., 1984. Cerebral asymmetries: neuropsychological measurement and theoretical issues. Biological Psychology 19, 295–304.

Mohr, C., Graves, R.E., Gianotti, L.R., Pizzagalli, D., Brugger, P., 2001. Loose but normal: a semantic association study. Journal of Psycholinguistic Research 30, 475–483.

O'Reilly, T.O., Dunbar, R., Bentall, R., 2001. Schizotypy and creativity: an evolutionary connection? Personality and Individual Differences 31, 1067–1078.

Park, S., Lee, J., Folley, B.S., Anderson, A., Kim, J., 2004. Components of working memory deficits in schizophrenia: integrating evidence from cognitive, fMRI and DTI studies. Biological Psychiatry 55, 43S–44S.

Petsche, H., 1996. Approaches to verbal, visual and musical creativity by EEG coherence analysis. International Journal of Psychophysiology 24, 145–159.

Pizzagalli, D., Lehmann, D., Brugger, P., 2001. Lateralized direct and indirect semantic priming effects in subjects with paranormal experiences and beliefs. Psychopathology 34, 75–80.

Poreh, A.M., Whitman, D.R., Ross, T.P., 1994. Creative thinking ability and hemispheric asymmetry in schizotypal college students. Current Psychology Research and Reviews 12, 344–352.

Psychological Corporation, 1999. WASI Manual. Harcourt Brace, San Antonio.

Raine, A., 1991. The SPQ: a scale for the assessment of schizotypal personality based on DSM-III-r criteria. Schizophrenia Bulletin 17, 555–564.

Rawlings, D., Toogood, A., 1997. Using a 'taboo response' measure to examine the relationship between divergent thinking and psychoticism. Personality and Individual Differences 22, 61–68.

Razoumnikova, O.M., 2000. Functional organization of different brain areas during convergent and divergent thinking: an EEG investigation. Brain Research Cognitive Brain Research 10, 11–18.

Razumnikova, O.M., 2004. Gender differences in hemispheric organization during divergent thinking: an EEG investigation in human subjects. Neuroscience Letters 362, 193–195.

Regard, M., Strauss, E., Knapp, P., 1982. Children's production of verbal and nonverbal fluency tasks. Perceptual and Motor Skills 55, 839–844.

Richardson, A.J., 1994. Dyslexia, handedness and syndromes of psychosis-proneness. International Journal of Psychophysiology 18, 251–263.

Rodel, M., Cook, N.D., Regard, M., Landis, T., 1992. Hemispheric dissociation in judging semantic relations: complimentarity for close and distant associates. Brain and Language 43, 448–459.

Rushton, J.P., 1990. Creativity, intelligence, and psychoticism. Personality and Individual Differences 11, 1291–1298.

Rust, J., Golombok, S., Abram, M., 1989. Creativity and schizotypal thinking. Journal of Genetic Psychology 150, 225–227.

Sato, H., Kiguchi, M., Kawaguchi, F., Makia, A., 2004. Practicality of wavelength selection to improve signal-to-noise ratio in near-infrared spectroscopy. Neuroimage 21, 1554–1562.

Schachter, S.C., Ransil, B.J., Geschwind, N., 1987. Associations of handedness with hair color and learning disabilities. Neuropsychologia 25, 269–276.

Seger, C.A., Desmond, J.E., Glover, G.H., Gabrieli, J.D., 2000. Functional magnetic resonance imaging evidence for right-hemisphere involvement in processing unusual semantic relationships. Neuropsychology 14, 361–369.

Shaw, J., Claridge, G., Clark, K., 2001. Schizotypy and shift from dextrality: a study of handedness in a large non-clinical sample. Schizophrenia Research 50, 181–189.

Shimkunas, A.M., Murray, D.R., 1974. Assessment of change in conventional and unconventional thought processes of schizophrenics. Journal of Personality Assessment 38, 32–40.

Spitzer, M., Braun, U., Hermle, L., Meier, S., 1993. Associative semantic network dysfunction in thought-disordered schizophrenic patients: direct evidence from indirect semantic priming. Biological Psychiatry 34, 864–877.

Spreen, O., Strauss, E., 1998. A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary. Oxford University Press, New York.

Torrance, E.P., 1988. The nature of creativity as manifest in 15 testings. In: Sternberg, R.J. (Ed.), The Nature of Creativity. Cambridge University Press, New York, pp. 43–75.

Venables, P.H., 1989. The Emmanual Miller lecture 1987: childhood markers for adult disorders. Journal of Child Psychology and Psychiatry and Allied Disciplines 30, 347–364.

Wallach, M.A., 1971. The Intelligence/Creativity Distinction. General Learning Press, New York.

Wallach, M.A., Kogan, N., 1965. Modes of Thinking in Young Children: A Study of the Creativity and Intelligence Distinction. Holt, Rinehart and Winston, New York.

Weinstein, S., Graves, R.E., 2001. Creativity, schizotypy, and laterality. Cognitive Neuropsychiatry 6, 131–146.

Weinstein, S., Graves, R.E., 2002. Are creativity and schizotypy products of a right hemisphere bias? Brain and Cognition 49, 138–151.

Weisbrod, M., Maier, S., Harig, S., Himmelsbach, U., Spitzer, M., 1998. Lateralised semantic and indirect semantic priming effects in people with schizophrenia. British Journal of Psychiatry 172, 142–146.

Woody, E., Claridge, G., 1977. Psychoticism and thinking. British Journal of Social and Clinical Psychology 16, 241–248.

Zanes, J., Hatfield, R., Houtler, B., Whitman, D., 1998. The relationship between creativity and psychosis-proneness. Personality and Individual Differences 24, 879–881.